Canada Mortgage and Housing Corporation

Société canadienne d'hypothèques et de logement

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TESTING OF AIR BARRIER SYSTEMS FOR WOOD FRAME WALLS

CLIENT REPORT

Prepared for: Canada Mortgage and Housing Corporation
682 Montreal Road
Ottawa, Ontario
K1A 0P7

Report No: CR5505.1
Report date: 3 June 1988
Contract No. CR5505
Reference: Application for test dated 13 April 1987
Section: Building Performance

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CLIENT REPORT

for

Canada Mortgage and Housing Corporation

Testing of Air Barrier Systems for Wood Frame Walls

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SUMMARY

The objective of this project was to measure the air leakage and structural performance of air barrier systems intended for use in wood frame walls. Measurements were performed using a test apparatus and procedure which were developed at IRC and which are described in the report.

Ten specimens were tested - nine constructed with wood studs and one constructed with steel studs. The systems were chosen by CMHC in cooperation with manufacturers of air barrier systems and materials, and in consultation with IRC. The test results are summarized in the report and listed in detail in the Appendix.

BACKGROUND

Uncontrolled air leakage through building envelopes can lead to a number of problems in the performance of buildings. These problems include higher than necessary energy cost, poor temperature and humidity control, and deposition of moisture in the building envelope. The latter problem can lead to deterioration of the building envelope.

Air leakage can be controlled by an air barrier system, i.e., a continuous plane of air tightness designed and constructed into the building envelope. This plane of air tightness may be achieved with a single strong air-tight material or a combination of materials. In either case, the assembly must be structurally capable of withstanding the air pressure load exerted on the building envelope. In addition, the air barrier system must be attached to the building in such a way that the load is transmitted to the structure of the building.

The materials in the air barrier system may be those which make up the fabric of the building, or they may be materials which have been added specifically to improve air tightness. In all cases it is important that the various materials in the "plane of air tightness" be joined with strong, leak-free joints.

Air Leakage Rate

It is reasonable to assume that the prime requirement of an air barrier system is control of air leakage. A properly designed air barrier system will have very low leakage at the operating pressure differences typically encountered in buildings. These "typical" pressure differences will be less than 20 Pa in low rise buildings under calm conditions. Pressure differences as high as 1000 Pa may be induced by wind, but, because of the duration of application, these are

generally of less importance in the consideration of total air leakage.

Test procedures which standardize the performance of building components (e.g., windows, curtain walls, doors) specify that a test for air leakage be conducted at a pressure difference of 75 Pa. These procedures also specify a "pass-fail" leakage rate at this pressure difference. The tests are performed using ASTM E 283 - Standard Test Method for Rate of Air Leakage Through Windows, Curtain Walls and Doors.

A similar test procedure can be used to measure the air leakage of air barrier systems. However, neither a standard test pressure difference nor an acceptable leakage rate can be specified at present. To circumvent this problem, a leakage performance curve (i.e., flow vs pressure difference) can be determined for air barrier systems using the apparatus specified in ASTM E 283. It should be noted that determination of air leakage performance by this method is more time consuming than a simple "pass/fail" test for air leakage at a specified pressure difference.

Building Science Insight'86, entitled "An Air Barrier for the Building Envelope", suggested an allowable leakage rate of 0.10 $l/s/m^2$ at 75 Pa pressure difference for buildings of moderate humidity level. This figure was determined from consideration of a number of factors including the levels currently permitted for curtain walls. While the figure was presented 'for discussion purposes only', it does suggest the order of magnitude of what might be accepted as a "pass/fail" air leakage rate.

Structural Performance

An additional requirement for an air barrier system is that of structural performance. This requirement arises because the system must be capable of resisting the pressure differences exerted on it in order to control air leakage. Over the life of a building, the air barrier system will be subjected to pressure differences resulting from stack effect, wind (both steady and gust loading) and possibly fan pressurization.

From a structural viewpoint, pressure differences resulting from stack effect are relatively small (<20 Pa) in low-rise residential buildings. These pressure differences have the potential, however, to produce plastic flow leading to "creep" failure in some air barrier system materials, e.g., sealants, tapes. This mode of failure would only occur after application of the pressure difference for an extended period of time. It is not reasonable to test an entire air barrier system for "creep" failure - such tests are better performed at the material level. However,

accelerated test procedures to evaluate this phenomenon are not available at present and further work on the properties of these materials is required.

The main forces which must be considered in the structural performance of air barrier systems are those that result from pressure differences induced by wind. These include sustained wind loads, lasting up to one hour, and gust loads lasting from 3-5 seconds.

Test pressure differences to simulate sustained wind loading can be determined from the design wind pressures tabulated in Chapter 1 of the Supplement to the National Building Code. The values tabulated for the 1 in 30 chance of occurrence were chosen as the basis for the sustained wind load test pressure difference. The maximum value in this table is on the order of 1000 Pa, although the majority are below 500 Pa. Three test pressure differences, 250 Pa, 500 Pa and 1000 Pa, were chosen as the test points at which to simulate sustained wind loading. These pressure differences were also used as points at which to determine air leakage rate.

Test pressure differences to simulate gust wind loading can also be determined from the National Building Code. In this case, the procedure for calculating gust loads on cladding was used to determine the worst case load condition for low rise construction. The results of this calculation showed that a pressure difference of 2500 Pa is the highest expected for any Canadian location. As with sustained wind loading, the design pressure difference for the majority of locations in Canada is considerably lower than this figure. Based on this calculation, three test pressure differences of 1500 Pa, 2000 Pa and 2500 Pa were chosen as the test points at which to simulate gust wind loading.

Test procedures which standardize the performance of building components specify that a test for structural performance be performed using ASTM E 330 - Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls and Doors by Uniform Air Pressure Difference. The same test protocol can be used to measure the structural performance of air barrier systems.

TEST PROCEDURE

The specimen was installed in the test apparatus with the plane of air tightness facing out. This procedure was adopted in order that structural changes to the specimen could be observed as they occurred. Testing on a specimen was terminated when the specimen was observed to have sustained significant structural damage.

Air leakage and structural performance tests were conducted on the specimens using both negative and positive pressure differences. For the purposes of this report, pressure difference is defined as negative when the pressure on the apparatus side of the specimen was less than the pressure on the laboratory side; it would pull the plane of air tightness onto the studs. Positive pressure difference would push the plane of air tightness off the studs. The negative pressure difference tests, both air leakage and structural performance, were always performed first since they were less likely to cause structural damage.

Air Leakage Rate Test

Where possible, the air leakage rate of the specimens was measured at pressure differences between 10 Pa and 100 Pa. The minimum test pressure difference for a number of the tighter specimens was raised to that which produced the minimum measurable flow rate (~0.002 $l/s/m^2$). The maximum test pressure difference for the two tightest specimens had to be increased beyond 100 Pa in order to obtain sufficient test points.

The pressure difference at each test point was held for a minimum of five minutes to allow time for the flow rate to stabilize. A flow-pressure equation of the form

$$Q/A = a*\Delta P^n$$

was fitted to the air leakage rate test data and to the data from the sustained load structural performance test.

Structural Performance Test

Sustained loading on the specimen was simulated by subjecting the specimen to pressure differences of 250 Pa, 500 Pa and 1000 Pa. Each of these pressure differences was held for a duration of one hour. The flow-pressure curve was extended to 1000 Pa pressure difference by measuring air flow during the three sustained load tests.

Gust loading on the specimen was simulated by subjecting the specimen to pressure differences of 1500 Pa, 2000 Pa and 2500 Pa. Each of these pressure differences was held for a duration of 5 to 10 seconds.

Following each structural performance test point, the specimen was examined for visual signs of structural damage and then the flow rate ('verification air flow rate') was measured at approximately 75 Pa pressure difference. For those specimens which did not show signs of structural damage, the verification air flow rate was compared to that calculated using the flow-pressure equation ('calculated air flow rate') as a further check for structural damage. For

those specimens which showed signs of structural damage, the verification air flow rate indicated the effect of the structural damage on the air tightness of the air barrier system.

TEST APPARATUS

The test apparatus (Figure 1a) conforms, in general, to those described in ASTM standards E 283 and E 330. It consists of an air tight steel test chamber with a double neoprene gasket (Figure 1b) mounted to the perimeter of the face of the apparatus. A 2.4 m x 2.4 m square test specimen is clamped to the face of the apparatus using screw clamps, five of which are located on each side of the apparatus.

Every effort was made to seal the perimeter of the test specimens against extraneous perimeter leakage. Tests performed on the apparatus before commencement of the project indicated that the perimeter sealing system was effective. This is confirmed by the fact that the air leakage of the specimens did not vary significantly between the pressurization and depressurization portions of the tests.

Positive and negative pressure differences are applied across the specimen by pressurizing or depressurizing the plenum between the specimen and the chamber. One of two fans is used to supply the air flow and pressure difference requirements of the test apparatus. The smaller of these has a maximum flow rate of 18 l/s while the larger has a maximum flow rate of 65 l/s.

Air flow rate was measured by one of three laminar flow elements (Meriam Instruments, Models 50MJ10, 20MW20-2 and 50MC2-4). The smallest of these measured a minimum flow rate of approximately 0.002 $l/s/m^2$; the largest measured a maximum flow rate greater than 3 $l/s/m^2$. The calibration curve provided with the laminar flow elements was verified by comparison with a calibrated flow measuring device at a number of flow levels. The readings compared within 1% at all test points.

Pressure drop across the laminar flow element and pressure in the plenum were measured by electronic micromanometers (Air Instrument Resources Ltd., Model MP3KDμ) with a resolution of 0.1 Pa at the lower range. The pressure in the plenum was referenced to the pressure in the laboratory, which was the pressure on the outside of the specimen. The calibration of the micromanometers was verified by comparison to a Betz manometer three times during the series of tests.

A schematic of the instrumentation is shown in Figure 1c.

TEST SPECIMENS

All test specimens, except specimen 6, were constructed by IRC following details of construction provided by CMHC. Specimen 6 was a prefabricated system that was constructed by the proponent of the system and delivered to the IRC laboratory.

Pine lumber was used for the studs and other lumber components in those specimens constructed by IRC. Other components of the specimens were either supplied by the proponent of the system or purchased from local suppliers. Fastening schedules were those provided by the proponent of the system through CMHC.

All specimens were constructed with two studs around the perimeter ('perimeter studs') to provide a surface for clamping the specimen to the apparatus. The joint between the studs was sealed on the inside surface with aluminum tape.

The principal materials in each test specimen are listed in Table 1. Table 1 also notes five specimens that were tested in two configurations for air leakage rate. Detailed descriptions of each test specimen are recorded in the Appendix.

RESULTS

Detailed results of the tests performed on each specimen are recorded in the Appendix. Figures 2 and 3 display the composite air leakage and structural performance results respectively from all ten specimens.

Air Leakage Rate Test

For all specimens except 8 and 10, the pressure difference exponent, n, was at or close to 1 (see Figure 2). This is a characteristic of laminar flow and indicates that these specimens are leaking through porous materials (or very tight joints). Specimens 8 and 10 exhibit a flow characteristic between laminar (n=1) and fully developed turbulent (n=0.5) flow. This indicates that some combination of both flow regimes is occurring, probably at cracks in the specimen. Specimens 1 and 2, which relied on spun bonded polyolefin paper as the air tightness component, were the leakiest; specimen 4, which used 38 mm extruded polystyrene with 3M construction tape at the joints, was the tightest.

Structural Performance Test

Eight specimens passed all steps of the negative pressure difference structural test; specimens 1 and 2 were too leaky to be tested at all steps but passed those at which they were tested. Seven specimens (see Figure 3) failed at some step in the positive pressure difference structural test. The majority of failures occurred at the fasteners. In most cases the specimen would have passed all steps with modified fastening systems.

Table 1. Principal Materials in Test Specimens
(See Appendix for a detailed description)

NUMBER	MATERIALS
1	Fiberboard sheathing covered with Tyvek paper and strapping
2	Glasclad insulation with taped joints and with a) untaped nail heads and b) taped nail heads
3	Exterior gypsum board and Perm-a-barrier tape
4	Extruded polystyrene insulation with taped joints and with a) untaped nail heads and b) taped nail heads
5	Esclad Energy Envelope insulation with taped joints and with a) untaped nail heads and b) taped nail heads
6	Prefabricated Dryvit system - exterior gypsum board and expanded polystyrene insulation with synthetic finish
7	Interior gypsum board with finished joints
8	Plywood skin wall panel with a) both plywood skins intact and b) two 2" (51 mm) holes drilled in each stud space of one plywood skin
9	Sprayed-in-place polyurethane in stud cavity on fiberboard sheathing with a) perimeter taped and b) perimeter untaped
10	Polyethylene sheet sandwiched between fiberboard sheathing and interior gypsum board

Note: All specimens, except specimen 6, were constructed with 38 mm x 89 mm wood studs. Specimen 6 was prefabricated with steel studs.

Figure 1a. Air leakage test apparatus (viewed from the rear).

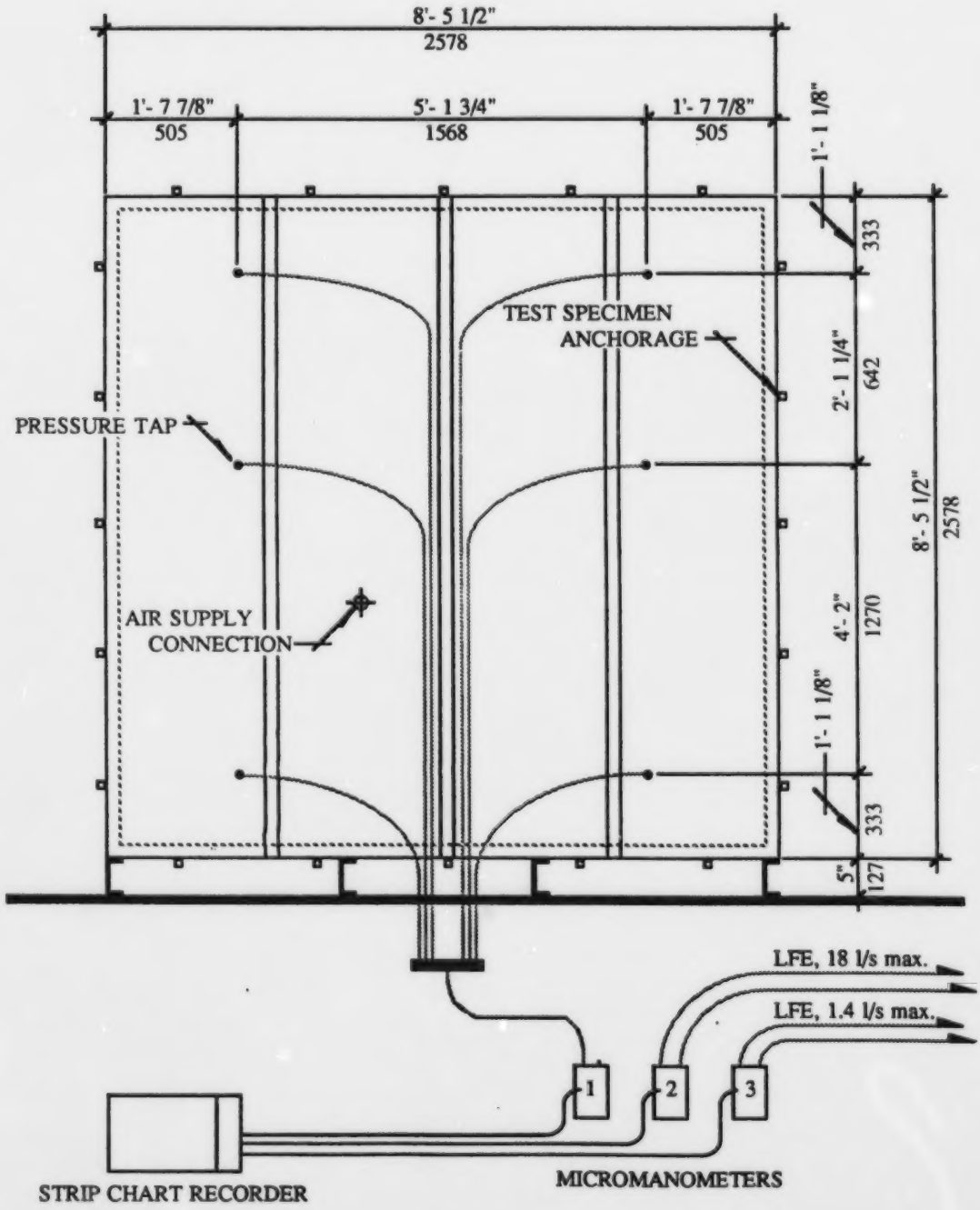


Figure 1b. Test box/test specimen connection.

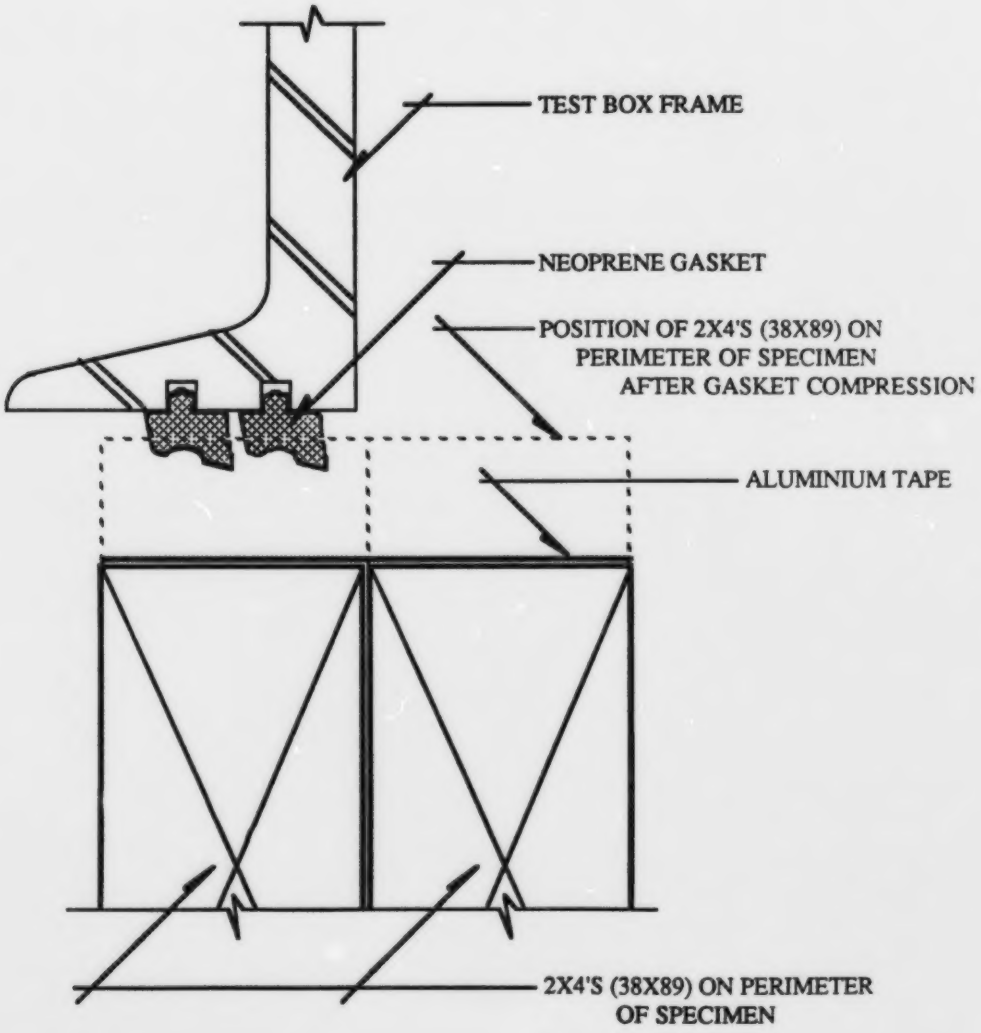


Figure 1c. Schematic of test instrumentation.

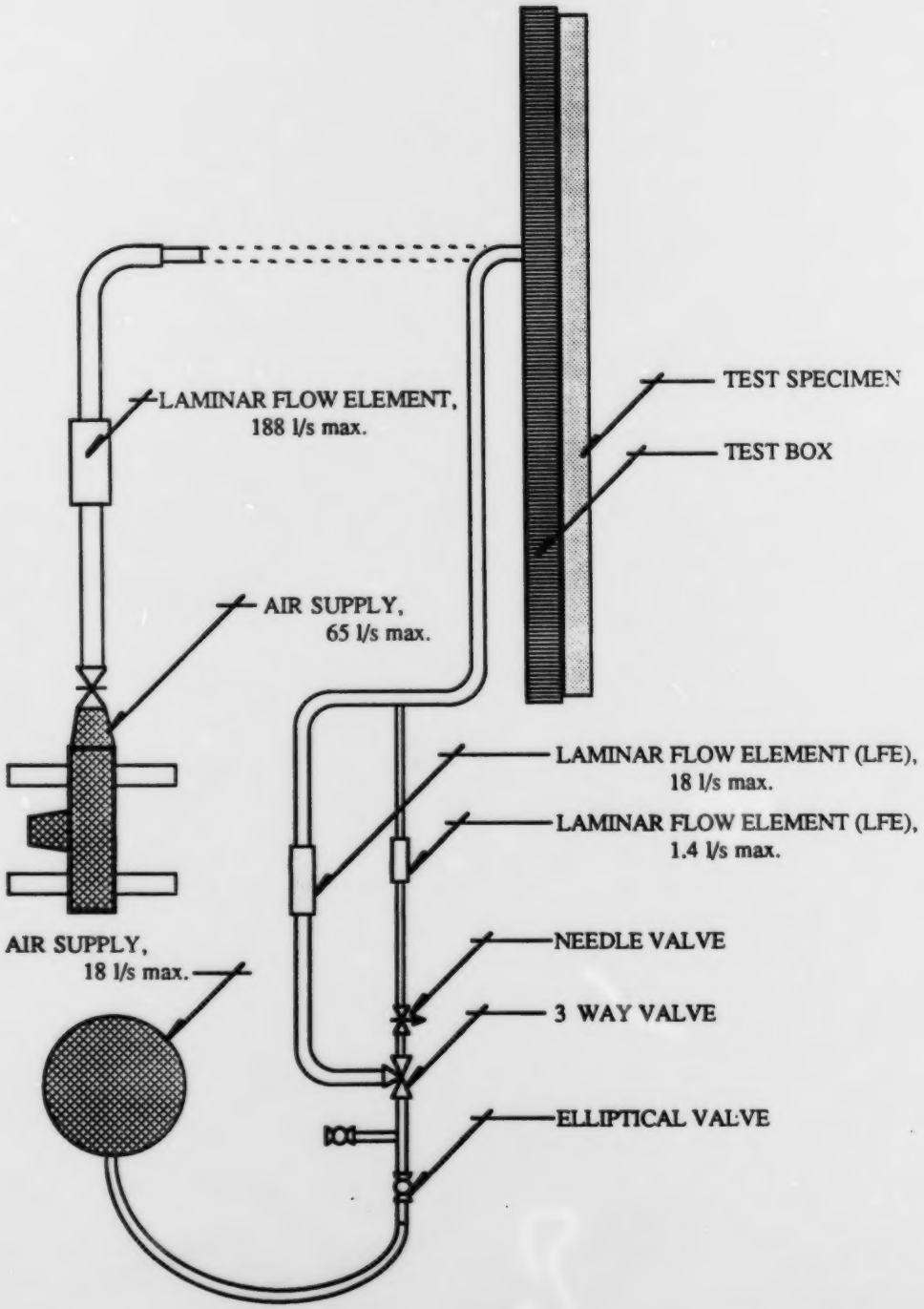


Photo 1. Test apparatus (with test specimen #8 installed).

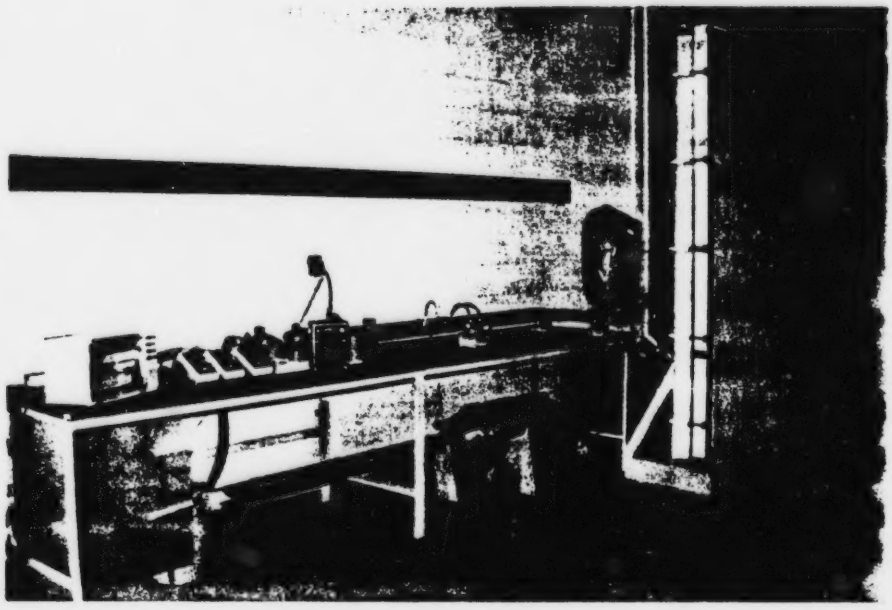


Figure 2. Air leakage test results.

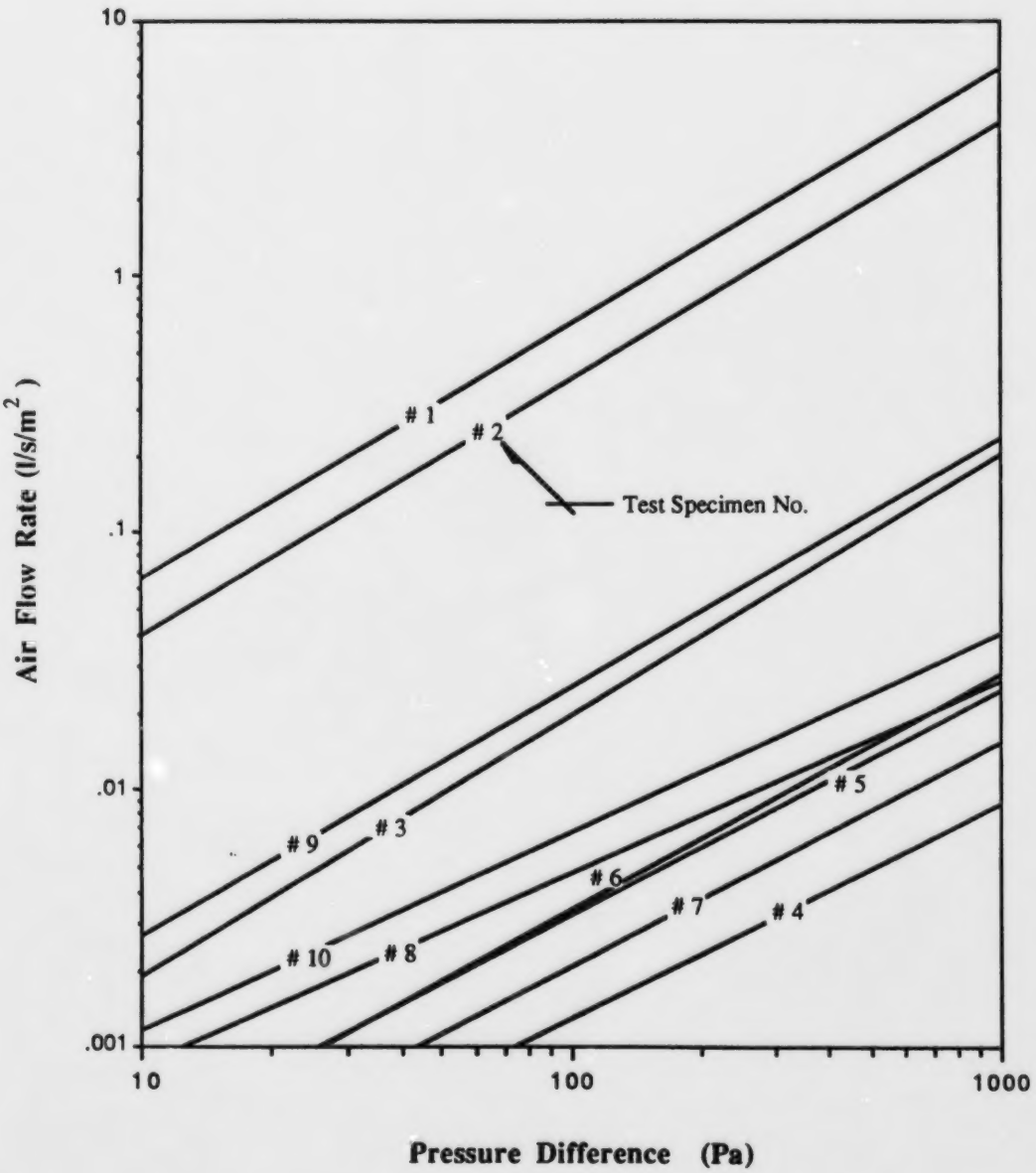
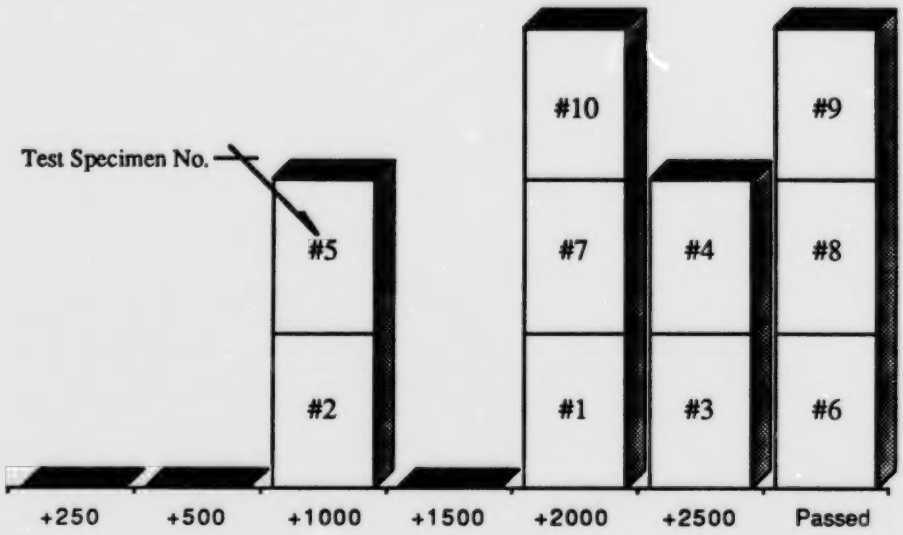


Figure 3. Structural perfcrmance test results.



Pressure Difference (Pa) at Which Specimen Failed

Note:

None of the test specimens failed structurally under negative pressure difference. However, test specimen # 1 was too leaky to be tested, under negative and positive pressure differences, at 2.0 kPa and 2.5 kPa. Test specimen # 2 was too leaky to be tested at -2.5 kPa.

APPENDIX

Detailed results from each specimen are contained on the following pages. The page numbering scheme consists of the specimen number followed by a page sequence number.

The presentation of these results conforms to the following format.

A. Description

This is a general description of the specimen and includes 'As Built Details' requested by the client. Drawings showing details of construction are included. They are dimensioned in feet-inches, as designated by the client, and millimeters.

B. Air Leakage Rate Tests

Measured air flow versus pressure difference data is presented in graphical format. Also shown on the graph is an equation of the form

$$Q/A = a*\Delta P^n$$

that was obtained from a least squares fit to the data from the negative and positive pressure difference tests. The coefficient of determination (r^2) was at or close to 1 for all specimens.

C. Structural Performance Tests

i) Sustained Load Tests
and
ii) Gust Load Tests

The verification test pressure difference (~75 Pa for most specimens) and verification air flow rate is tabulated for each structural test point. Included for comparison is the air flow rate calculated at the verification test pressure difference using the flow-pressure equation. The pressure difference at which structural failure was observed to occur is also noted.

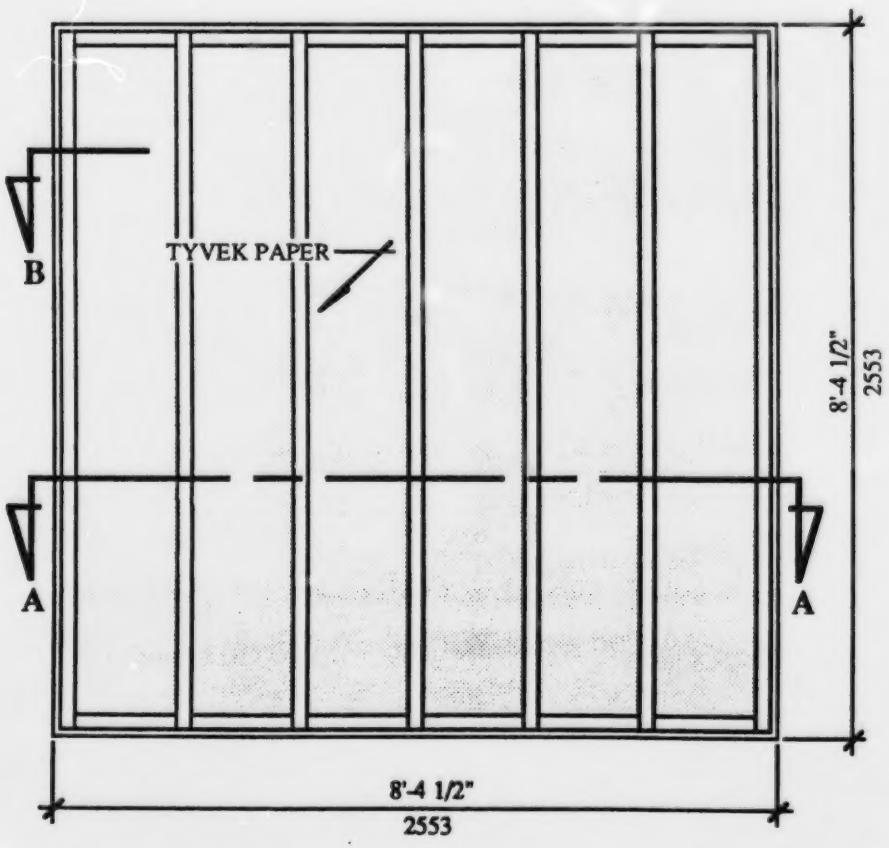
D. Observations and Comments

Observations and comments on the performance of the specimen and mode of failure, if failure occurred, are provided. Suggestions on how to improve the performance of the system may also be included.

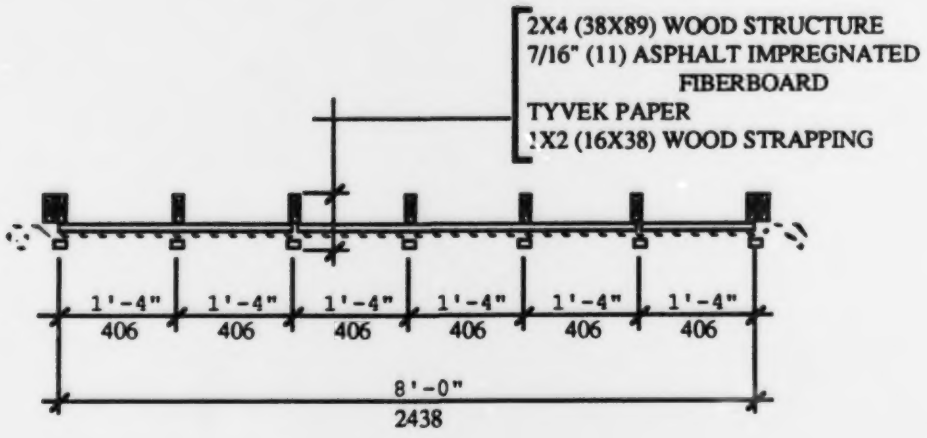
Test Specimen #1

A) Description

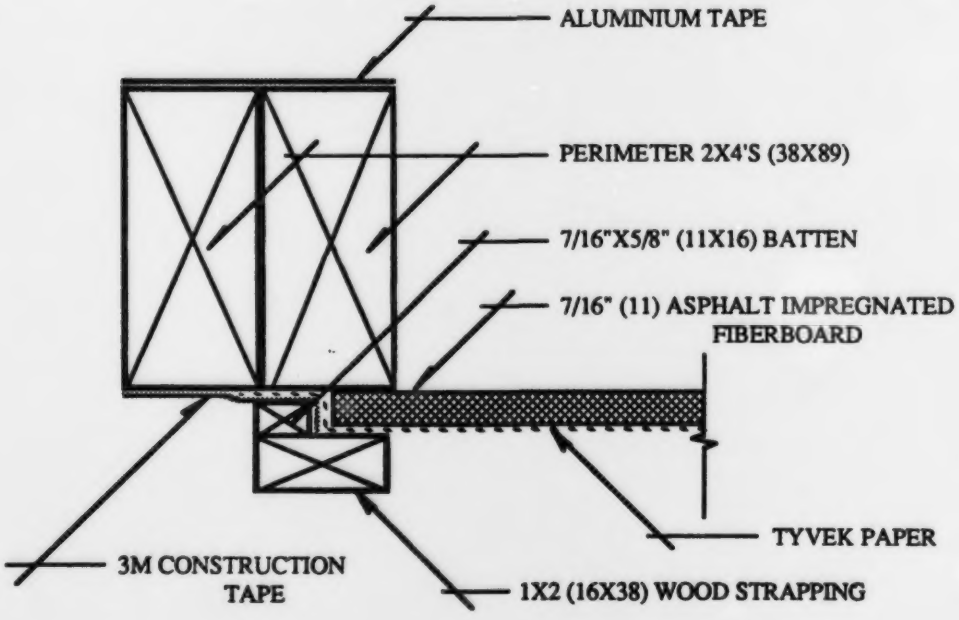
Test specimen #1 was a three component air barrier system consisting of a fiberboard sheathing, a Tyvek paper, and wood vertical strapping. In such a system the fiberboard and the strapping are structural components and the Tyvek paper is the air tightness component. The air tightness line of the air barrier system was carried to the test box by taping the Tyvek paper to the perimeter 2X4's (38X89) with 3M construction tape (see " DETAIL B ").



FRONT VIEW



SECTION AA



DETAIL B

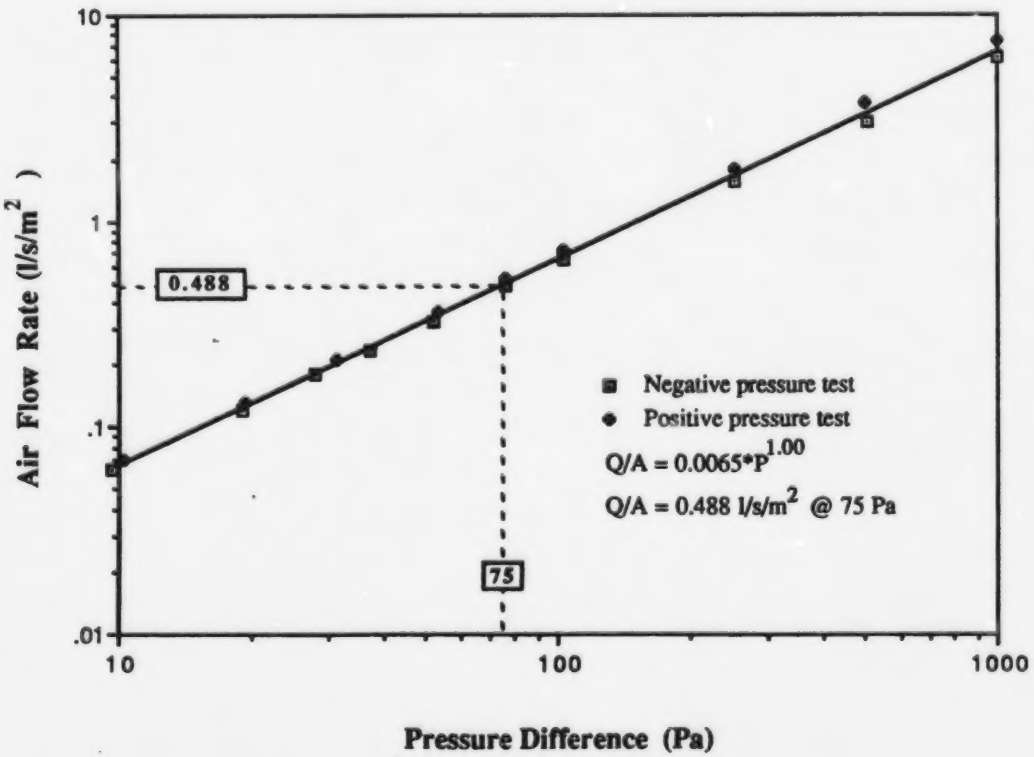
As Built Details:

i) The fiberboard sheathing was nailed to the wood structure with 1 3/4" (45) galvanized roofing nails at 6" (152) o.c. along the edges and 12" (305) o.c. along the intermediate supports.

ii) The Tyvek paper was temporarily attached to the fiberboard with 1/4" (6) staples every 4 (1219) feet prior to the installation of the wood strapping.

iii) 1X2 (16X38) wood strapping was nailed to the perimeter of the 2X4 (38X89) structure and to the face of the studs with 2 1/2" (64) spiral nails at 12" (305) o.c..

B) Air Leakage Rate Tests



C) Structural Performance Tests

i) Sustained Load Tests

(The test period of the sustained load tests was one hour)

Test Pressure (Pa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-250	-76.6	0.484	0.498
-500	-76.0	0.476	0.494
-1000	-76.2	0.476	0.495
+250	+75.4	0.524	0.490
+500	+74.5	0.524	0.484
+1000	+75.2	0.524	0.489

ii) Gust Load Tests

(The test period of the gust load tests was in the range of 5 to 10 seconds)

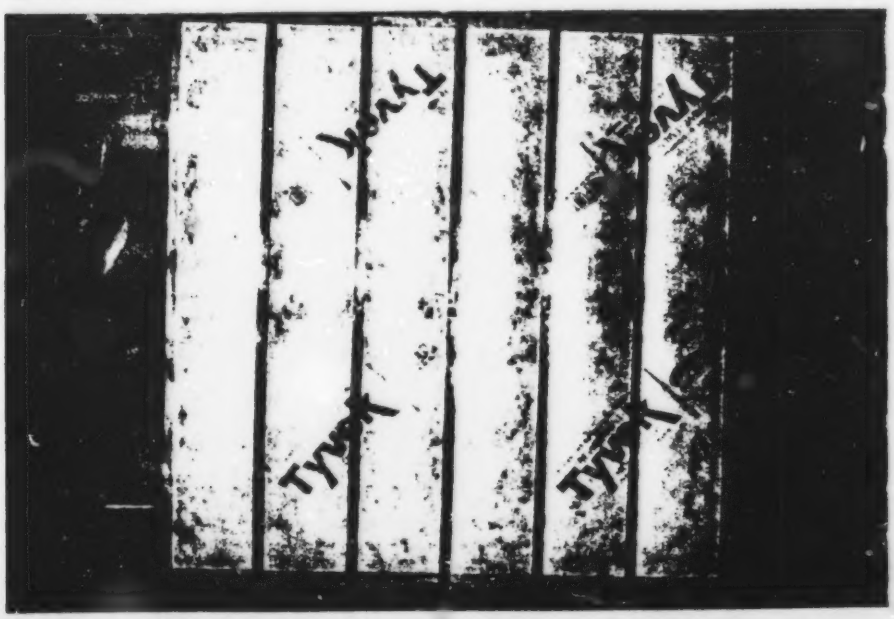
Test Pressure (kPa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-1.5	-76.0	0.476	0.498
-2.0	The system was too leaky for the air supply to produce these pressures		
-2.5			
+1.5	+75.2	0.524	0.490
+2.0	The system was too leaky for the air supply to produce these pressures		
+2.5			

D) Observations And Comments

The air leakage tests indicated an air leakage rate of 0.488 l/s/m^2 at 75 Pa for test specimen # 1. This value is approximately five times larger than the value suggested during the Building Science Insight'86 for moderate inside climate of 0.10 l/s/m^2 at a pressure difference of 75 Pa. Basically no change occured to the air leakage rate of the assembly after each structural test performed (see Section C).

In the structural performance tests, it was not possible to perform the 2.0 kPa and 2.5 kPa gust load tests for both positive and negative pressure differences because the test specimen was too leaky for the air supply capacity. With an air supply of 11 l/s/m^2 it was not possible to obtain a pressure difference across the assembly larger then 1.6 kPa under positive pressure and 1.8 kPa under negative pressure. However, the system performed structurally up to the 1.5 kPa sustained load test under both negative and positive pressure differences. Under positive pressure, the Tyvek paper ballooned outward between the wood strapping but did not slip off its fixation points (see Photo 1-1). After the +1000 Pa test, the paper had gained enough elongation from this action to leave it loose on the surface of the fiberboard sheathing. This physical change of the Tyvek paper did not change the air leakage rate of the system at 75 Pa. Such movements induce stress in the material at the point of fixation which could lead to the failure of the paper with time. A flexible air tightness component in the air barrier assembly can also introduce a pressure distribution within the wall components. If these components are not designed to sustain the load exerted on them, they might fail structurally.

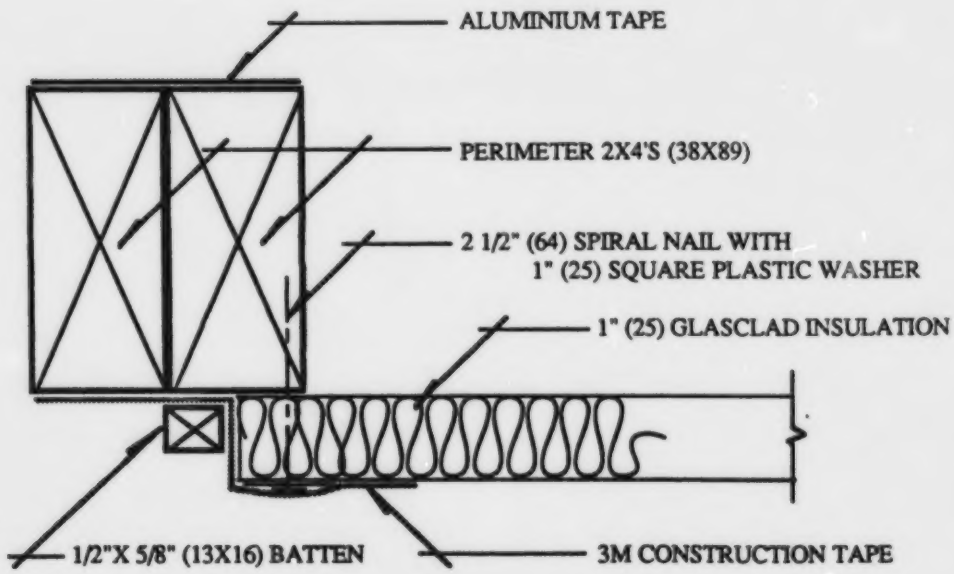
Photo 1-1:



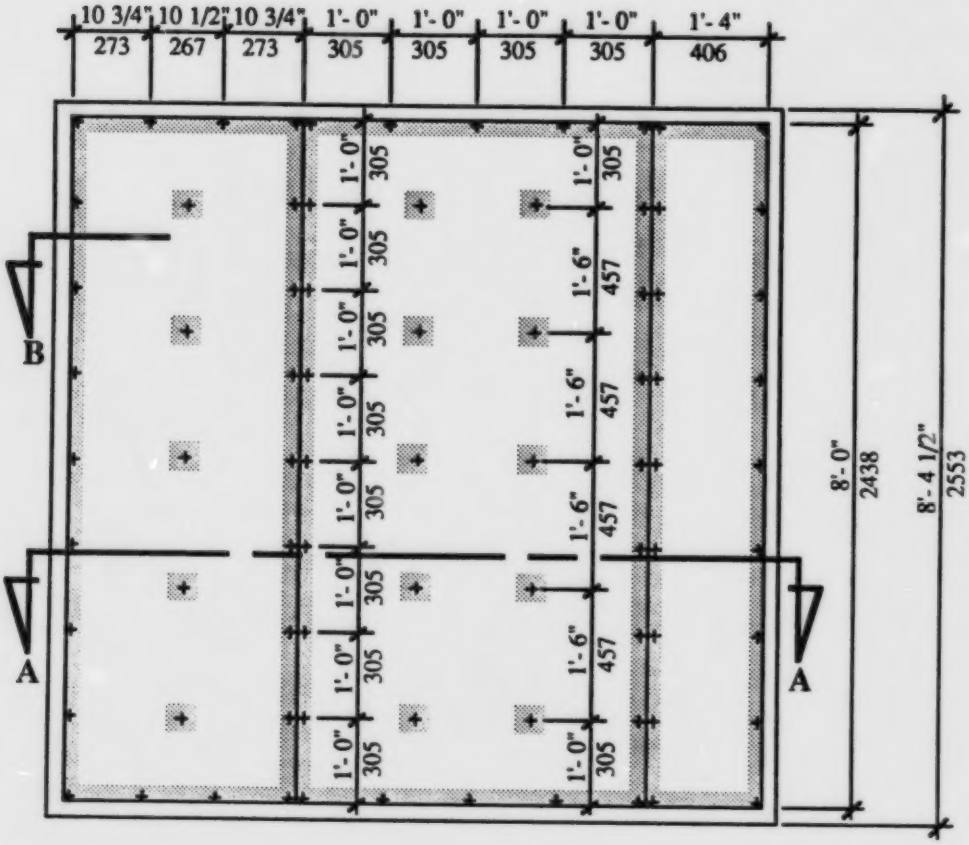
Test Specimen #2

A) Description

The air barrier system in test specimen # 2 consisted of Glasclad insulation boards and 3M construction tape. Glasglad insulation is a two component product made of a spunbonded polyolefin paper glued to the surface of a semi-rigid glass fiber insulation board. The polyolefin paper provides air tightness to the insulation material which on the other hand provides structure and rigidity to the paper. In such an air barrier system the air tightness line will exist at the spunbonded polyolefin paper. The 3M construction tape provides the air tightness continuity between the Glasclad insulation boards and at the nail perforations. The air tightness line of the system was carried to the test box by taping the polyolefin paper to the perimeter 2X4's (38X89) with 3M construction tape (see " DETAIL B ").

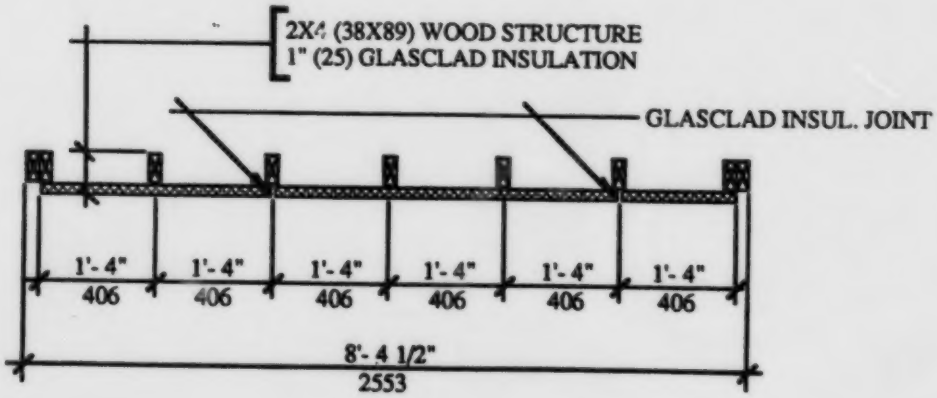


DETAIL B



FRONT VIEW

NOTE: 3M CONSTRUCTION TAPE, + NAILING POINT



SECTION AA

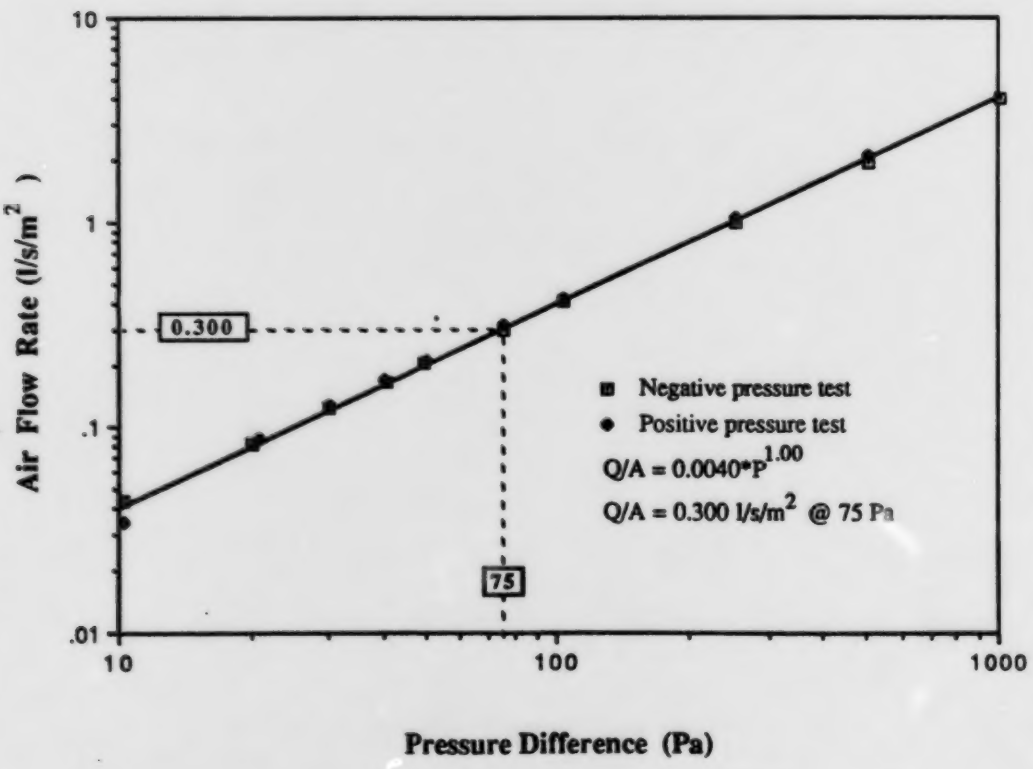
As Built Details:

i) Two vertical joints were provided within the air barrier system test specimen.

ii) Glasclad boards were nailed to the wood structure, as indicated on "FRONT VIEW", using 2 1/2" (64) spiral nails with 1" (25) square plastic washers.

iii) All joints and nail perforations were taped with 3M construction tape.

B) Air Leakage Rate Tests



C) Structural Performance Tests

i) Sustained Load Tests

(The test period of the sustained load tests was one hour)

Test Pressure (Pa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-250	-76.0	0.310	0.304
-500	-75.4	0.302	0.302
-1000	-75.2	0.302	0.301
+250	+76.2	0.326	0.305
+500	+76.2	0.326	0.305
+1000	Air barrier system failed on the first few minutes of the test.		

ii) Gust Load Tests

(The test period of the gust load tests was in the range of 5 to 10 seconds)

Test Pressure (kPa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-1.5	-75.2	0.302	0.301
-2.0	-75.2	0.302	0.301
-2.3*	-75.4	0.302	0.302
+1.5	These tests were not performed because the air barrier system failed on the		
+2.0	+ 1000 Pa sustained load test.		
+2.5			

* Maximum pressure difference attained with 11 $l/s/m^2$ air supply.

D) Observations And Comments

The air leakage tests indicated an air leakage rate of 0.300 l/s/m^2 at 75 Pa for test specimen # 2. This value is three times larger than the value suggested during the Building Science Insight'86 for moderate inside climate of 0.10 l/s/m^2 at a pressure difference of 75 Pa. Basically no change occured to the air leakage rate of the assembly after each structural test performed (see Section C). Two air leakage tests under negative pressure difference were performed for test specimen # 2. The first test was done with the nail perforations at the center of the Glasclad insulation boards not taped. The second test was done with the nail perforations taped. These two tests were performed to see how much the nail perforations contribute to the total air leakage rate of the assembly. The difference between the air leakage rate of the two configurations was negligible. The air leakage and the structural test results of the latter configuration of the test specimen are the ones reported.

In the structural test, it was not possible to perform the -2.5 kPa gust load test because the test specimen was too leaky for the air supply capacity. The maximum pressure difference obtained with the 11 l/s/m^2 air supply was -2.3 kPa. The air barrier assembly performed structurally under negative pressure up to this level. That is, after each test, the air leakage rate did not change and no physical failure of the structural components of the assembly was observed. However, deflection of the Glasclad insulation boards between each stud was quite noticeable during the -1000 Pa sustained load test (see Photo 2-1).

The gust load tests under positive pressure difference were not performed because the assembly failed during the first few minutes of the +1000 Pa sustained load test. Once the +1000 Pa pressure difference was reached the spunbonded polyolefin paper started to pull off from a few nails at a time, until only the upper left nail and the tape along the perimeter of the assembly were holding the paper in place. These failures caused the pressure to decrease to approximately +380 Pa. When an attempt was made to raise the pressure difference back to +1000 Pa, the paper pulled off from the last nail (see Photo 2-2). During the +250 Pa and +500 Pa sustained load tests it was observed that the polyolefin paper was delaminated from the glass fiber insulation at several locations. The delamination points were difficult to identify, except for the extreme case, where it was possible to detect an air pocket under the paper[1] .

---

[1]It is quite possible that the paper was delaminated at more locations then the ones observed because the Glasclad insulation was bulging outward between each point of fixation over the whole test surface, consequently masking the delaminated paper locations. When the pressure difference was reduced to zero and the material has relaxed, it was almost impossible to detect the delaminated locations on the paper.

Test specimen # 2 is weak on both air leakage and structural requirements of an air barrier system. The structural weakness of the air barrier system lies in its fixation technique to the supporting structure and in the composition of the Glasclad insulation which does not keep its structural integrity under positive pressure. The structural performance of the system might be improved by the addition of wood strapping.

Photo 2-1:

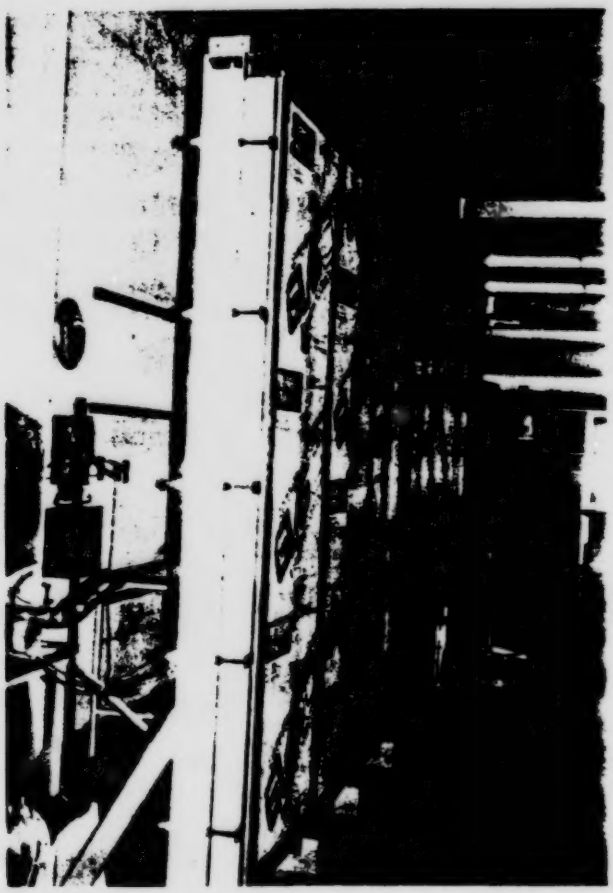
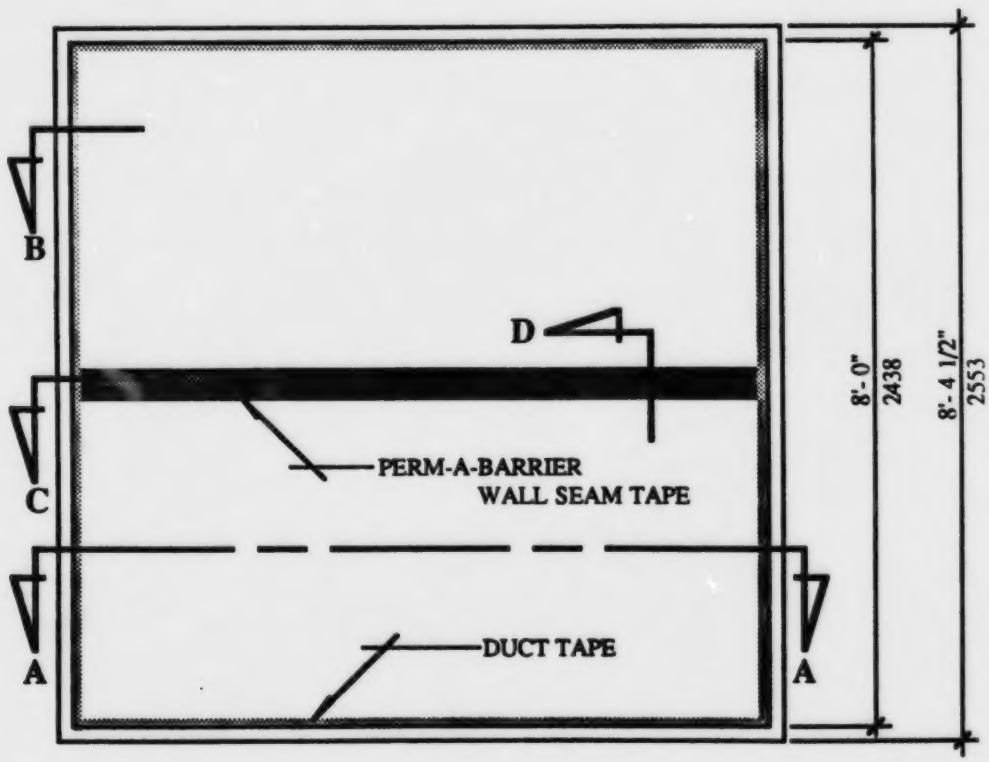


Photo 2-2:

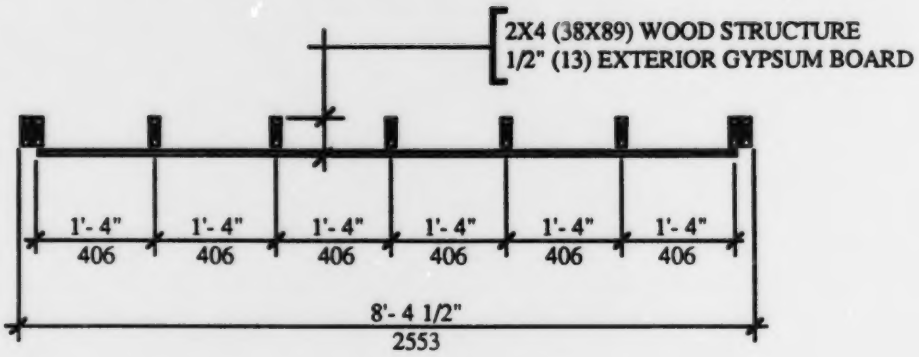
Test Specimen #3

A) Description

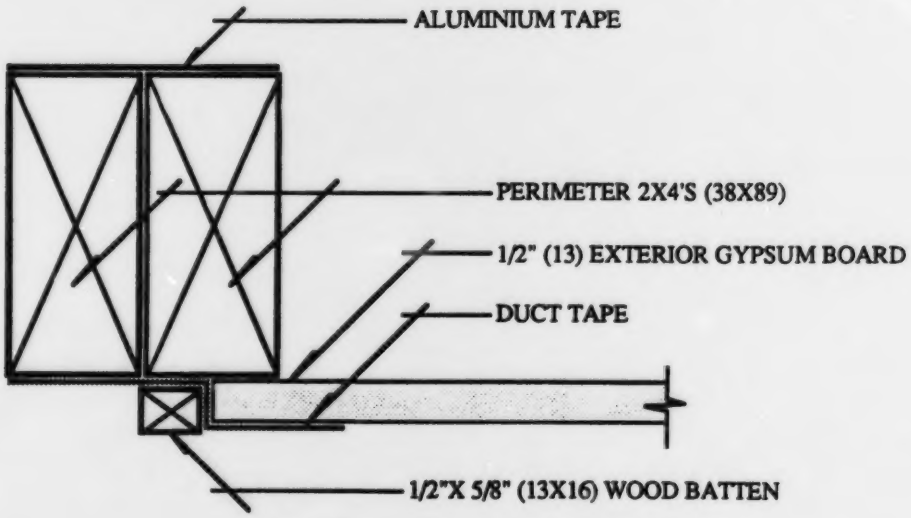
Test specimen # 3 consisted of two exterior gypsum boards installed horizontally and sealed at the joint with a Perm-A-Barrier wall seam tape. In such a design, the gypsum boards provide both the air tightness and the structural requirements in the air barrier system and the Perm-A-Barrier tape provides the air tightness continuity between gypsum boards. The air tightness line of the air barrier system was carried to the test box by taping the perimeter of the assembly to the perimeter 2X4's (38X89) with duct tape (see " DETAIL B "). Since duct tape does not provide a good seal when applied over a thin material with square edges, a piece of aluminium tape was used instead to make the air seal continuity at the overlap of the Perm-A-barrier tape (see " DETAIL C ").



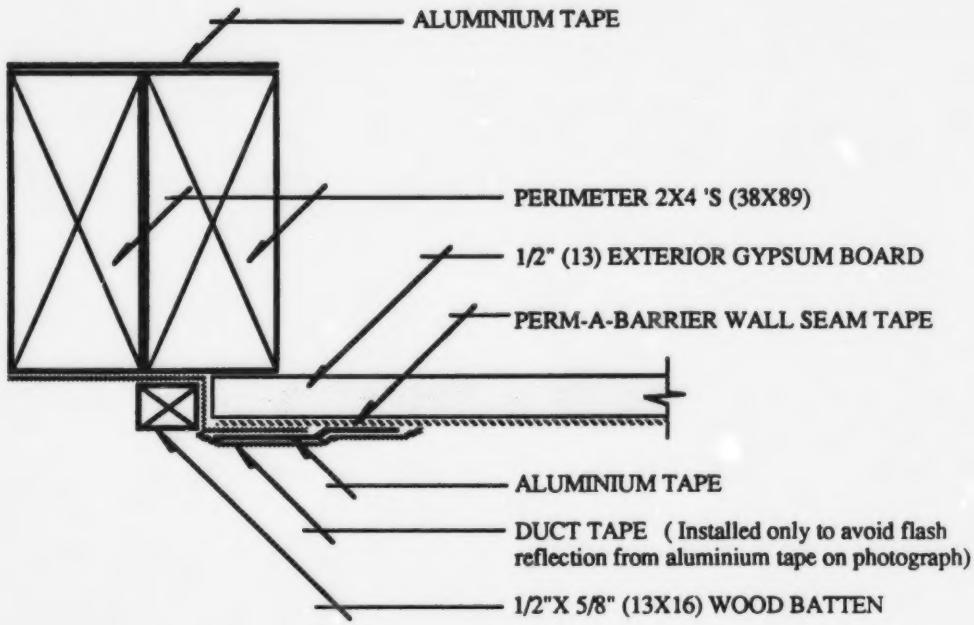
FRONT VIEW



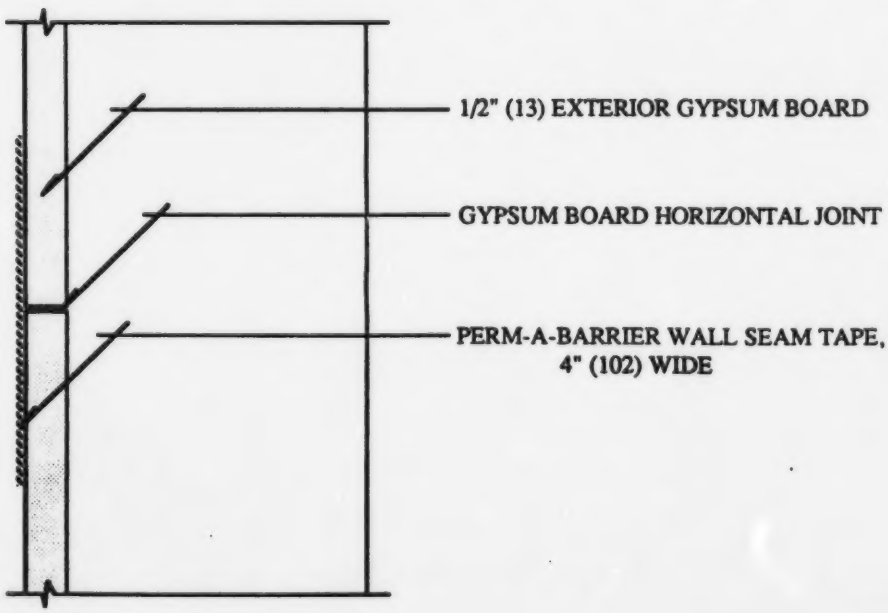
SECTION AA



DETAIL B


ALUMINIUM TAPE
PERIMETER 2X4 'S (38X89)
1/2" (13) EXTERIOR GYPSUM BOARD
PERM-A-BARRIER WALL SEAM TAPE
ALUMINIUM TAPE
DUCT TAPE (Installed only to avoid flash reflection from aluminium tape on photograph)
1/2"X 5/8" (13X16) WOOD BATTEN

DETAIL C



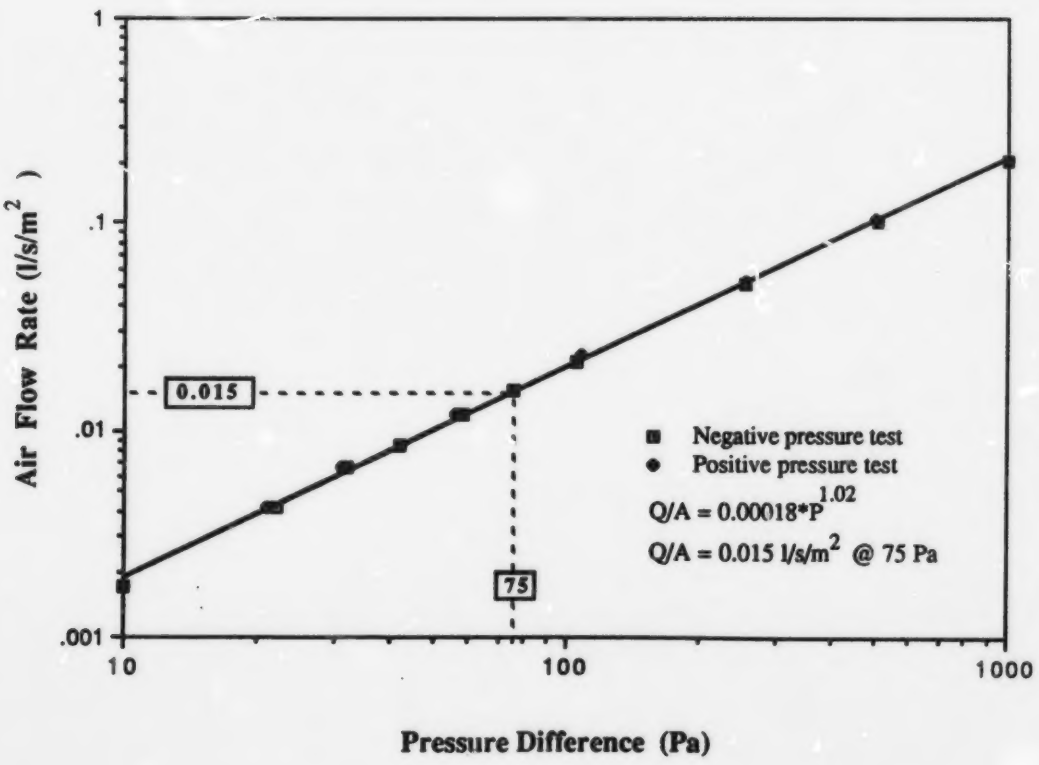
DETAIL D

As Built Details:

i) The 1/2" (13) gypsum boards were nailed horizontally to the wood structure with 1 3/4" (45) galvanized roofing nails at 6" (152) o.c. along the edges and at 12" (305) o.c. along the intermediate supports.

ii) The horizontal joint was sealed with 4" (102) wide Perm-A-Barrier wall seam tape. The gypsum boards surface receiving the tape was prepared with " Primer P- 3000" at least one hour before the application of the tape, as specified by the manufacturer.

B) Air Leakage Rate Tests



C) Structural Performance Tests

i) Sustained Load Tests

(The test period of the sustained load tests was one hour)

Test Pressure (Pa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-250	-75	0.015	0.015
-500	-76	0.015	0.015
-1000	-76	0.015	0.015
+250	+76	0.015	0.015
+500	+75	0.016	0.015
+1000	+76	0.016	0.015

ii) Gust Load Tests

(The test period of the gust load tests was in the range of 5 to 10 seconds)

Test Pressure (kPa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-1.5	-76	0.015	0.015
-2.0	-76	0.015	0.015
-2.5	-76	0.015	0.015
+1.5	+76	0.016	0.015
+2.0	+76	0.016	0.015
+2.5	+76	1.540	0.015

The air barrier system failed structurally at approximately +2.3 kPa.

D) Observations And Comments

The air leakage tests indicated an air leakage rate of 0.015 l/s/m^2 at 75 Pa for test specimen # 3. This value is approximately seven times smaller than the value suggested during the Building Science Insight'86 for moderate inside climate of 0.10 l/s/m^2 at a pressure difference of 75 Pa. The air leakage verification tests carried out after each of the structural tests, performed before the +2.5 kPa gust load test, indicated essentially no change in the air leakage rate of the assembly (see Section C). After the +2.5 kPa gust load test the air leakage rate increased to 1.540 l/s/m^2. This increase was caused by a structural failure of the assembly .

The air barrier system performed structurally through all the sustained load and gust load tests under negative pressure difference. That is, the air leakage rate did not change and no physical failure of the components of the asssembly was observed. Under positive pressure difference the system failed structurally during the 2.5 kPa gust load test. At a pressure difference of +2.3 kPa the top gypsum board pulled off from the nails along the intermediate supports. The only physical change noticed before the structural failure was after the +1000 Pa sustained load test where three nail heads, in the surface of the bottom gypsum board, had partially cut the paper (see Photo 3-1). No physical change or delamination of the Perm-A-Barrier tape were observed during the entire series of tests.

Test specimen # 3 air barrier system is very air tight but its attachment to the supporting structure requires more attention. Tighter nailing schedule, nails with larger head, or strapping are possible answers to the assembly attachment weakness. With a slight modification in its fixation to the supporting structure, test specimen # 3 could perform structurally through the specified structural tests.

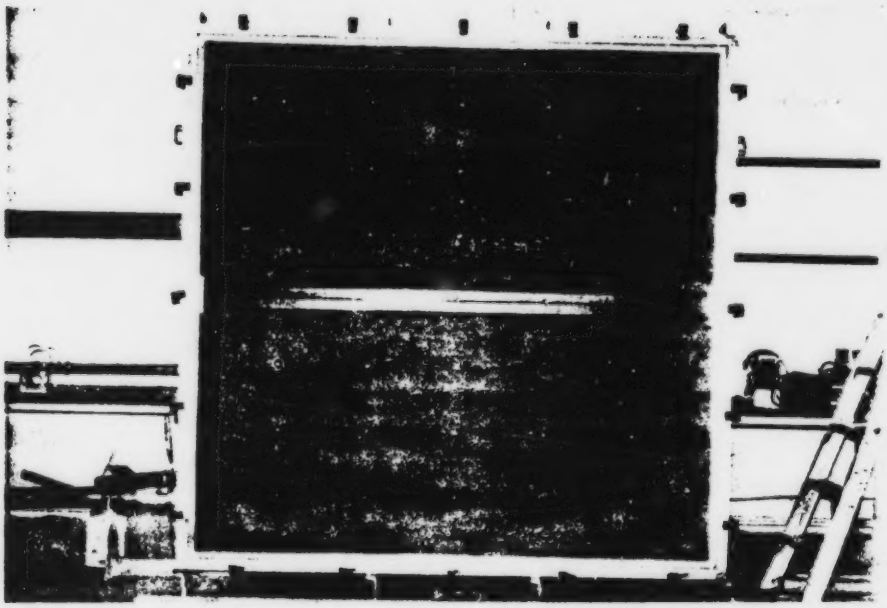


Photo 3-1:

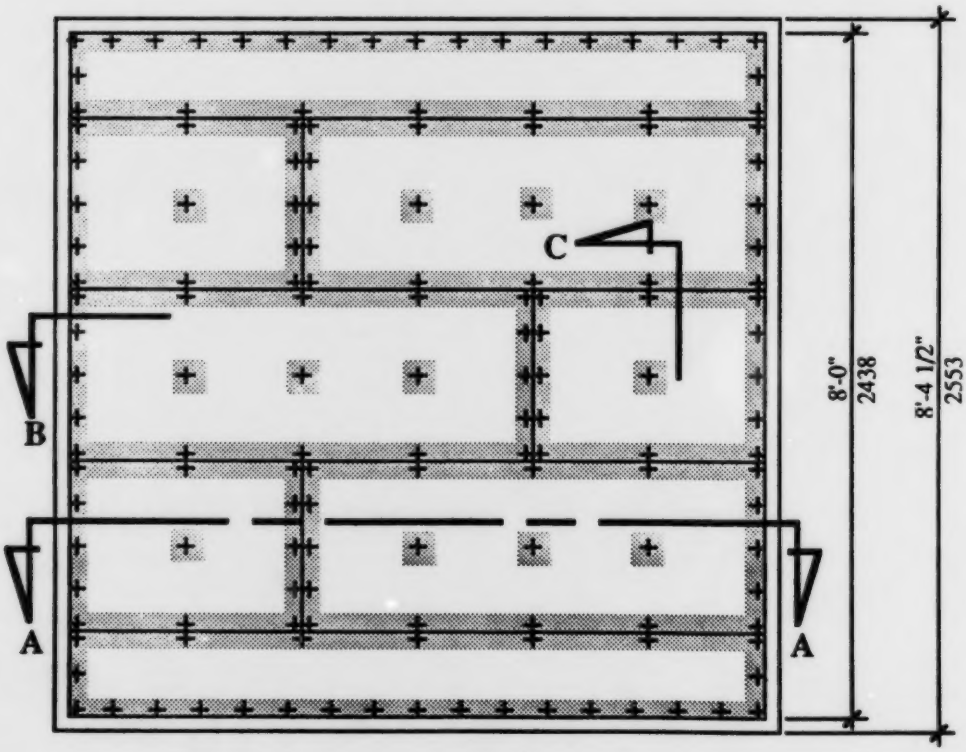
- Top gypsum board pulled off from the nails along the intermediate supports.

The white circles indicate where the nail heads partially cut the gypsum board paper.

Test Specimen #4

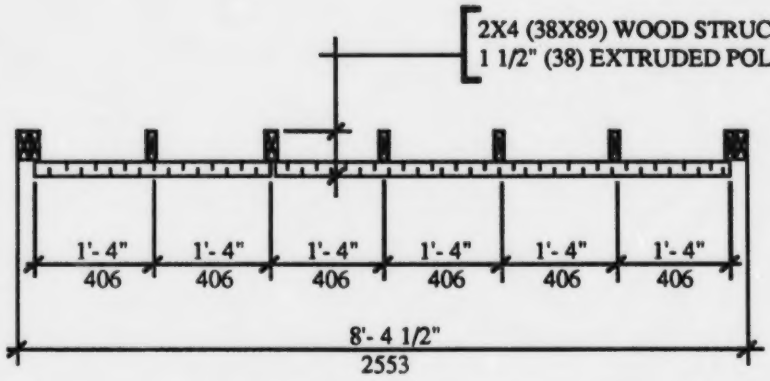
A) Description

The air barrier system of test specimen # 4 was made up of extruded polystyrene insulation boards and 3M construction tape. In this system, the polystyrene insulation provides both air tightness and structural requirements of the air barrier system. The 3M construction tape provides the air tightness continuity between the insulation boards shiplap joint (see " DETAIL C "). The test specimen air tightness line was carried to the test box by taping the perimeter of the assembly to the perimeter 2X4's (38X89) with 3M construction tape (see " DETAIL B "). The wood batten in " DETAIL B " provides structural support to the tape along the perimeter of the assembly.

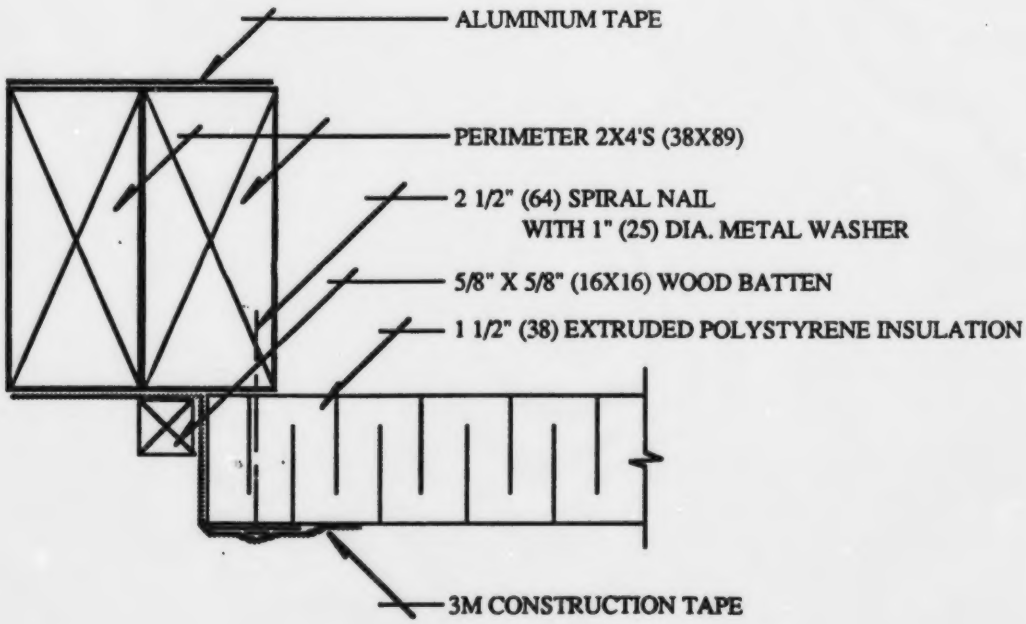


FRONT VIEW

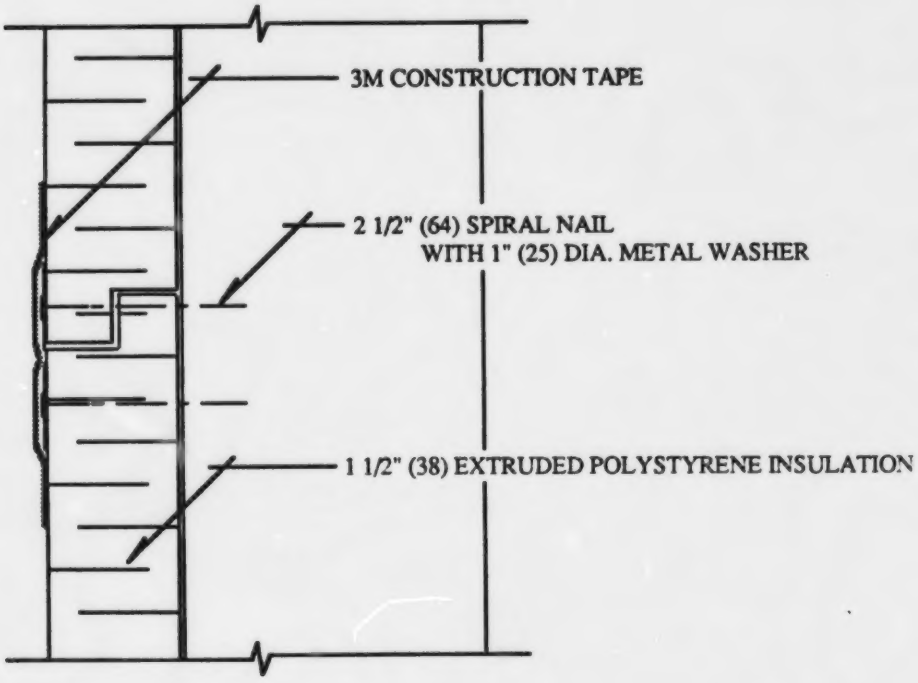
NOTE: ▒ 3M CONSTRUCTION TAPE, + NAILING POINT



SECTION AA


ALUMINIUM TAPE
PERIMETER 2X4'S (38X89)
2 1/2" (64) SPIRAL NAIL
WITH 1" (25) DIA. METAL WASHER
5/8" X 5/8" (16X16) WOOD BATTEN
1 1/2" (38) EXTRUDED POLYSTYRENE INSULATION
3M CONSTRUCTION TAPE

DETAIL B


3M CONSTRUCTION TAPE
2 1/2" (64) SPIRAL NAIL
WITH 1" (25) DIA. METAL WASHER
1 1/2" (38) EXTRUDED POLYSTYRENE INSULATION

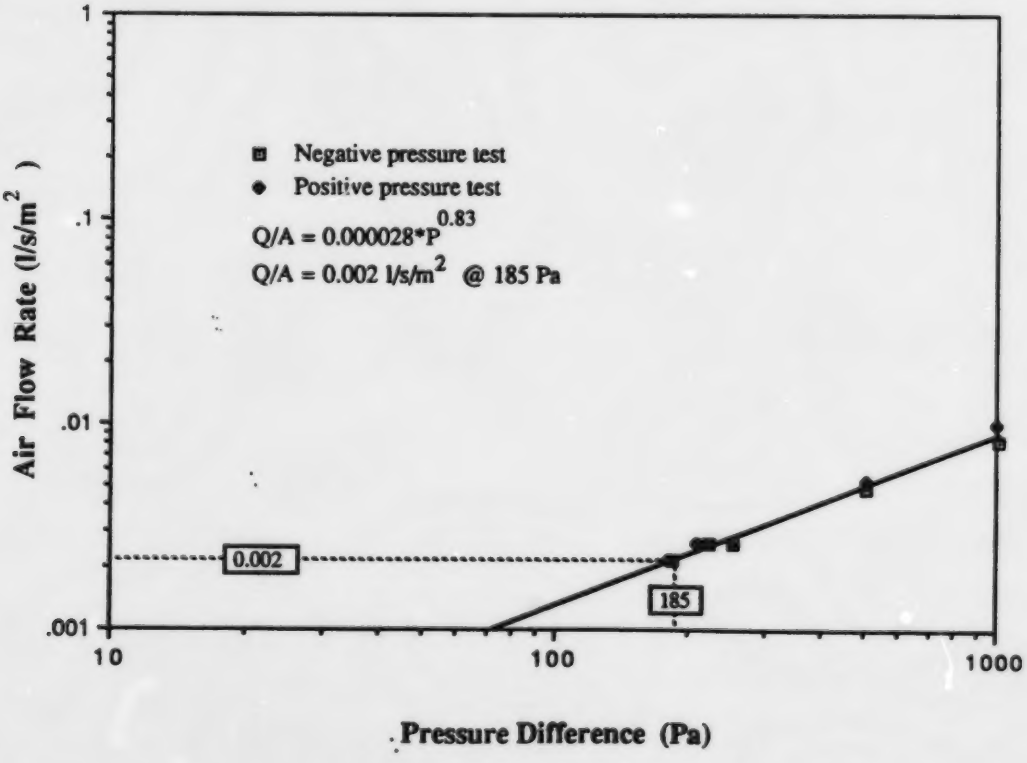
DETAIL C

As Built Details:

i) The extruded polystyrene insulation boards were nailed to the wood structure with 2 1/2" (64) spiral nails, with 1" (25) diameter metal washer, at every 6" (152) along the edges and 12" (305) along the intermediate supports.

ii) All insulation shiplap joints and nail heads were taped with 3M construction tape.

B) Air Leakage Rate Tests



C) Structural Performance Tests

i) Sustained Load Tests

(The test period of the sustained load tests was one hour)

Test Pressure (Pa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-250	-186	0.002	0.002
-500	-186	0.002	0.002
-1000	-186	0.002	0.002
+250	+180	0.002	0.002
+500	+180	0.002	0.002
+1000	+180	0.002	0.002

ii) Gust Load Tests

(The test period of the gust load tests was in the range of 5 to 10 seconds)

Test Pressure (kPa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-1.5	-185	0.002	0.002
-2.0	-186	0.002	0.002
-2.5	-186	0.002	0.002
+1.5	+180	0.002	0.002
+2.0	+180	0.002	0.002
+2.5	+180	0.005	0.002

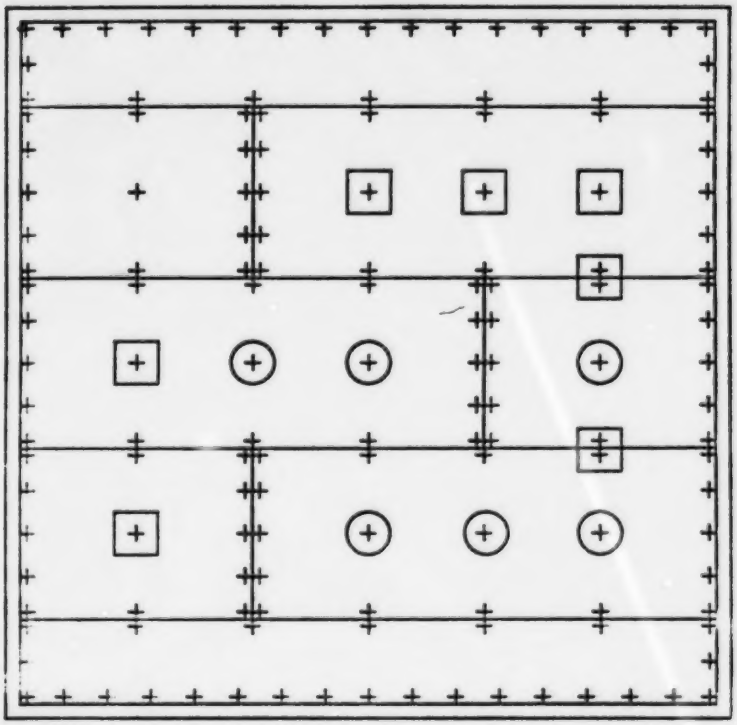
Structural failure occured at several nail locations during the +2.5 kPa test.

D) Observations And Comments

The air leakage tests indicated an air leakage rate of 0.002 l/s/m^2 at a pressure difference of 185 Pa for test specimen # 4. Because of the air tightness of the assembly and in order to obtain air leakage values for pressure differences below the sustained load test levels, the air leakage test pressure difference high limit was increased from 100 Pa to 225 Pa, and the reference air leakage rate pressure difference was increased from 75 Pa to 185 Pa. Two air leakage tests under both negative and positive pressure differences were performed on test specimen # 4. The first test was done with the nails at the center of the insulation boards not taped. The second air leakage test was done with the nails at the center of the insulation boards taped with 3M construction tape. The two air leakage tests were performed to see how much the nails at the center of the insulation boards contribute to the total air leakage rate of the assembly. No difference was measured. The test results of the second configuration of test specimen # 4 are the ones reported.

The air barrier system performed very well throughout the sustained load structural tests. The air leakage rate of the assembly did not change and no physical change of the assembly was observed during the visual inspections. However, the system failed structurally at certain nail locations during the +2.5 kPa gust load test. Some of the nails were pulled out of the stud and at some other locations the insulation material was compressed approximately 3 mm. The material compression was just enough to leave the washer hanging loose on the surface of the insulation when the pressure was released (see schematic and Photo 4-1 below). The air leakage rate increased from 0.002 l/s/m^2 to 0.005 l/s/m^2 at 180 Pa after the +2.5 kPa gust load test (see Section C).

Test specimen # 4 is very air tight but its attachment to the supporting structure requires some attention. Since nail perforations do not seem to be a problem for air leakage for this system, a tighter nailing schedule at the center of the insulation boards might give enough additional structural support to allow the system to perform the entire test procedure. The installation of strapping on top of the insulation is another possible solution.



FAILURE LOCATIONS

NOTE:

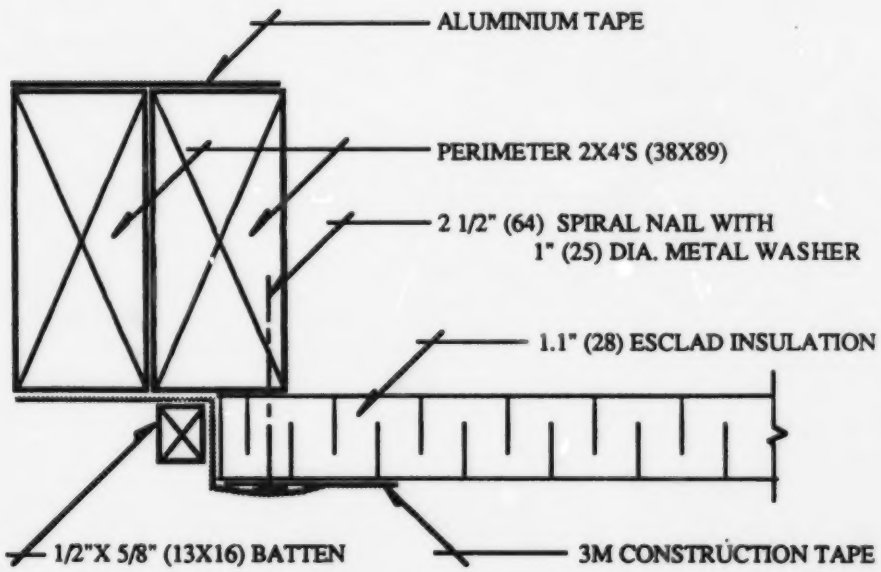
□ COMPRESSED INSULATION MATERIAL. ○ PULLED OUT NAIL

Photo 4-1:

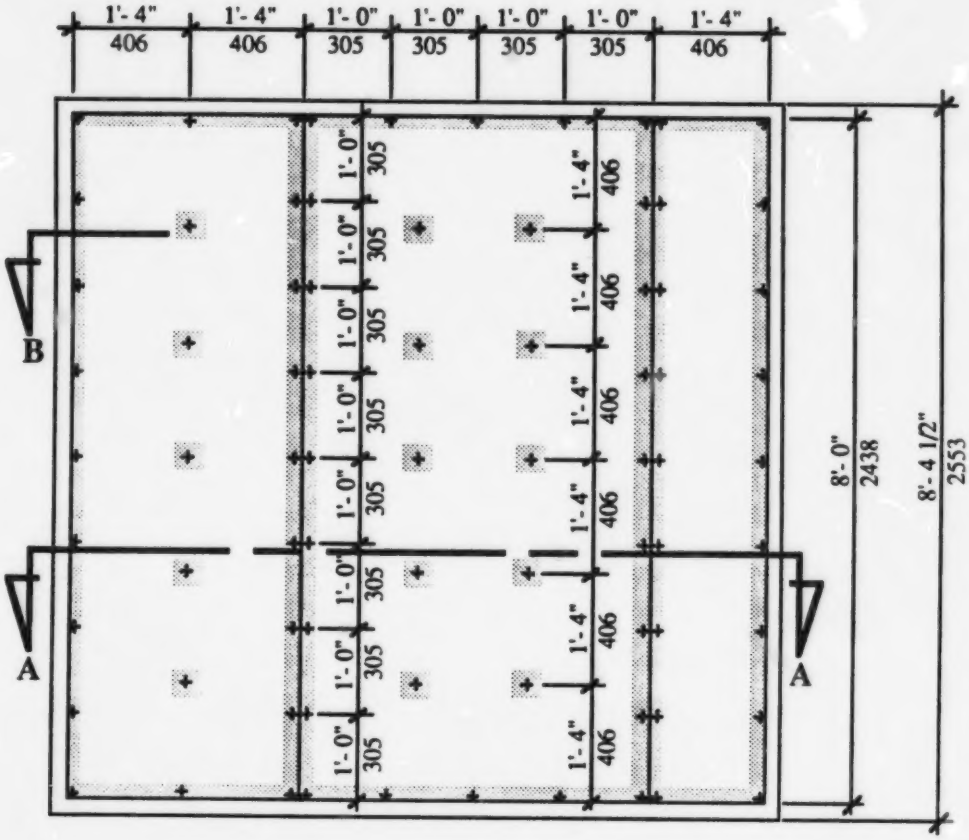
Test Specimen #5

A) Description

The air barrier system in test specimen # 5 consisted of a single layer of Esclad Energy Envelope boards and 3M construction tape. In this system the insulation boards provide both air tightness and structural requirements of the air barrier system. The 3M construction tape provides the air tightness continuity between the Esclad boards and at the nail perforations. The test specimen air tightness line was carried to the test box by taping the assembly to the perimeter 2X4's (38X89) with 3M construction tape. A wood batten was used to provide structural support to the tape along the air barrier assembly (see " DETAIL B ").

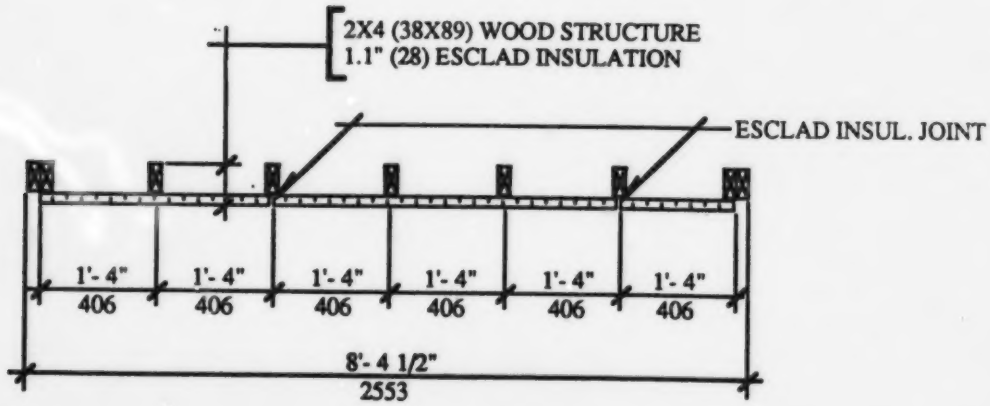


DETAIL B



FRONT VIEW

NOTE: CONSTRUCTION 3M TAPE, + NAILING POINT



SECTION AA

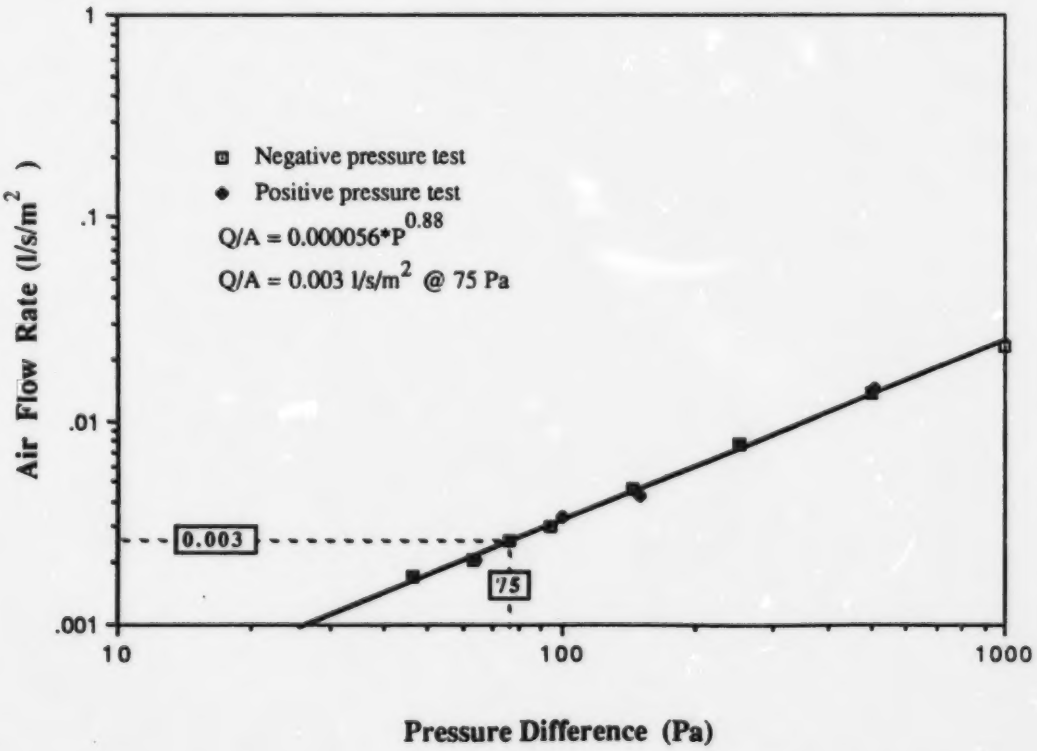
As Built Details:

i) Two vertical joints were provided within the air barrier system test specimen.

ii) The Esclad Energy Envelope boards were installed vertically with the printed side facing outward. The boards were nailed, as indicated on "FRONT VIEW", with specified 2 1/2" (64) spiral nails with 1" (25) diameter metal washers.

iii) All joints and nail perforations were taped with 3M construction tape.

B) Air Leakage Rate Tests



C) Structural Performance Tests

i) Sustained Load Tests

(The test period of the sustained load tests was one hour)

Test Pressure (Pa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-250	-76	0.003	0.003
-500	-75	0.003	0.003
-1000	-76	0.003	0.003
+250	+76	0.003	0.003
+500	+76	0.003	0.003
+1000	+76	0.119	0.003

Structural failure occured after 30 minutes of +1000 Pa loading.

ii) Gust Load Tests

(The test period of the gust load tests was in the range of 5 to 10 seconds)

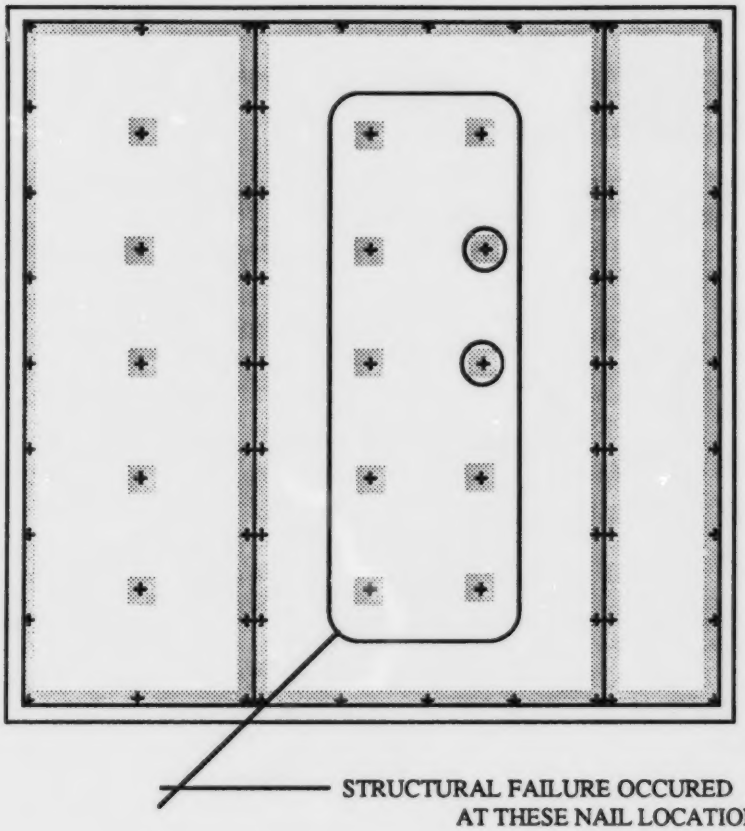
Test Pressure (kPa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-1.5	-76	0.003	0.003
-2.0	-75	0.003	0.003
-2.3	-76	0.003	0.003
+1.5	These tests were not performed because the air barrier system failed on the + 1000 Pa sustained load test.		
+2.0			
+2.5			

D) Observations And Comments

The air leakage tests indicated an air leakage rate of 0.003 l/s/m^2 at 75 Pa for test specimen # 5. This value is approximately thirty three times smaller than the value suggested during the Building Science Insight'86 for moderate climate of 0.10 l/s/m^2 at a pressure difference of 75 Pa. The test procedure was started by doing an air leakage test under both positive and negative pressure differences for two cases of test specimen # 5. In the first case the nails along the intermediate supports of the Esclad boards were left untaped. In the second case, all the nails along the intermediate supports were taped with 3M construction tape. By taping the nails along the intermediate supports the air impermeability of the assembly was improved by approximately six times. The air leakage and structural test results of the latter configuration of test specimen # 5 are the ones reported. Basically no change occured to the air leakage rate of the assembly after each test that was performed before the +1000 Pa pressure difference sustained load test (see Section C). After the +1000 Pa test, the air leakage of the assembly increased to 0.119 l/s/m^2. This increase was caused by a structural failure of the system.

The air barrier system performed very well during the structural tests under negative pressure differences but failed during the +1000 Pa pressure difference sustained load test. After 30 minutes of sustained loading at +1000 Pa, the larger Esclad board pulled off the nails along the intermediate supports except for two locations where the nail pulled out of the stud. No structural failure was observed in the insulation material along the edges of this Esclad board. No displacement or structural failure were observed in the two end insulation boards. See schematic and photographs below for the failure locations and type of failure. The ripped paper in " Photo 5-2 " is not the product of the tests but from the removal of the 3M construction tape for photographic purposes.

Test specimen # 5 air barrier system is very air tight but its attachment to the supporting structure requires more attention. A tighter nailing schedule at the center of the insulation boards might provide the additional structural support required to the system to perform the entire test procedure. Another possible solution is to use wood strapping, either horizontally or vertically, to support the Esclad insulation in place.



FAILURE LOCATIONS

NOTE: ○ PULLED OUT NAIL

Photo 5-1

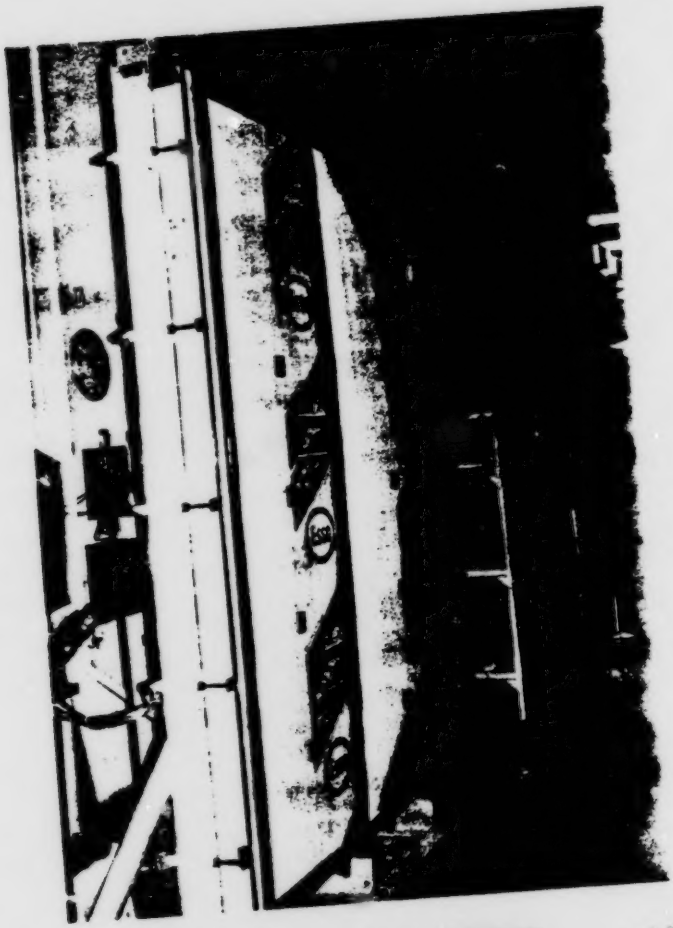
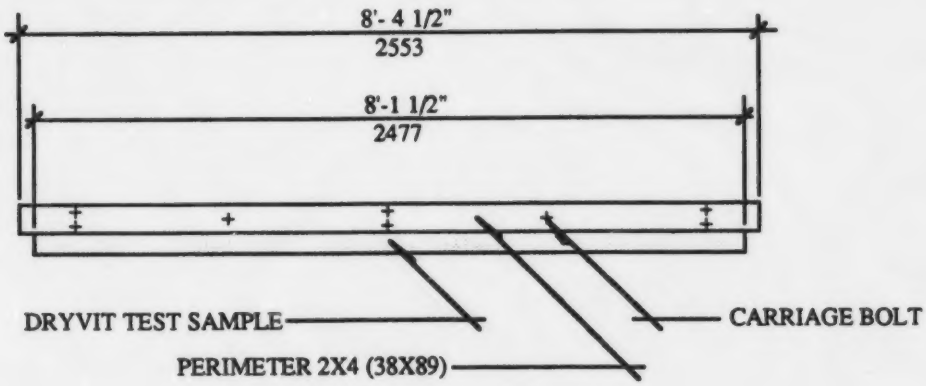


Photo 5-2

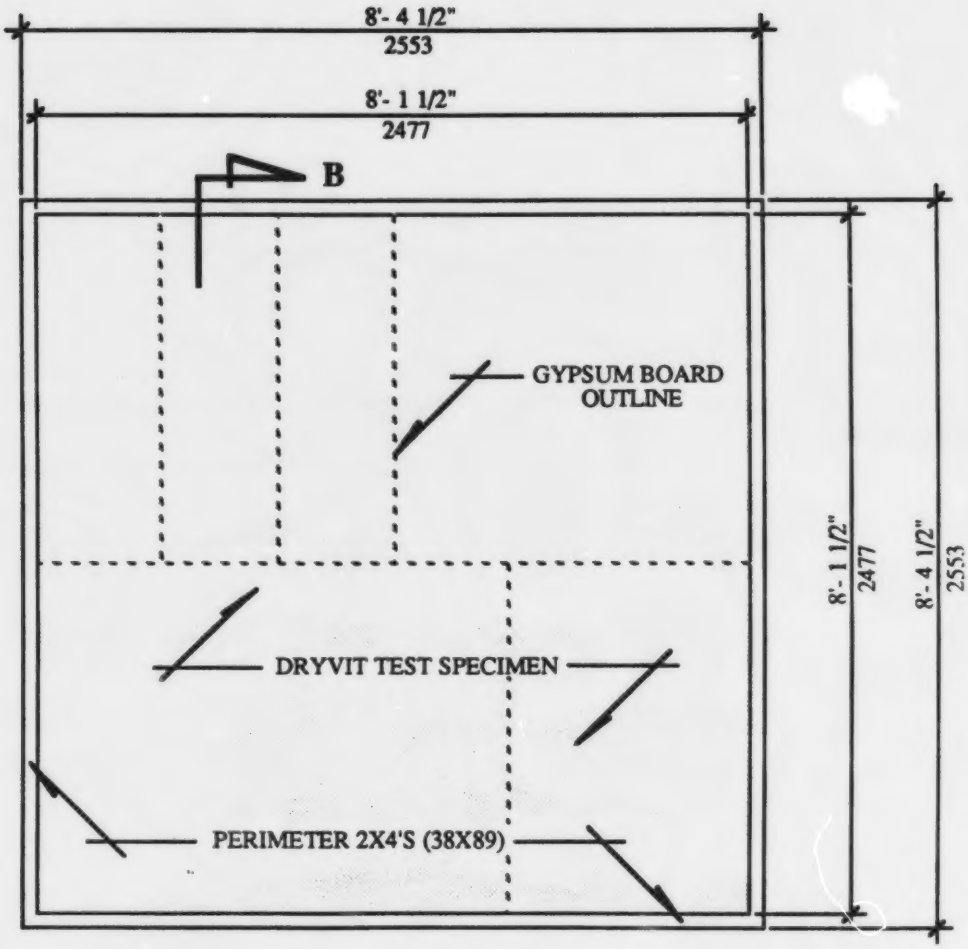
Test Specimen #6

A) Description

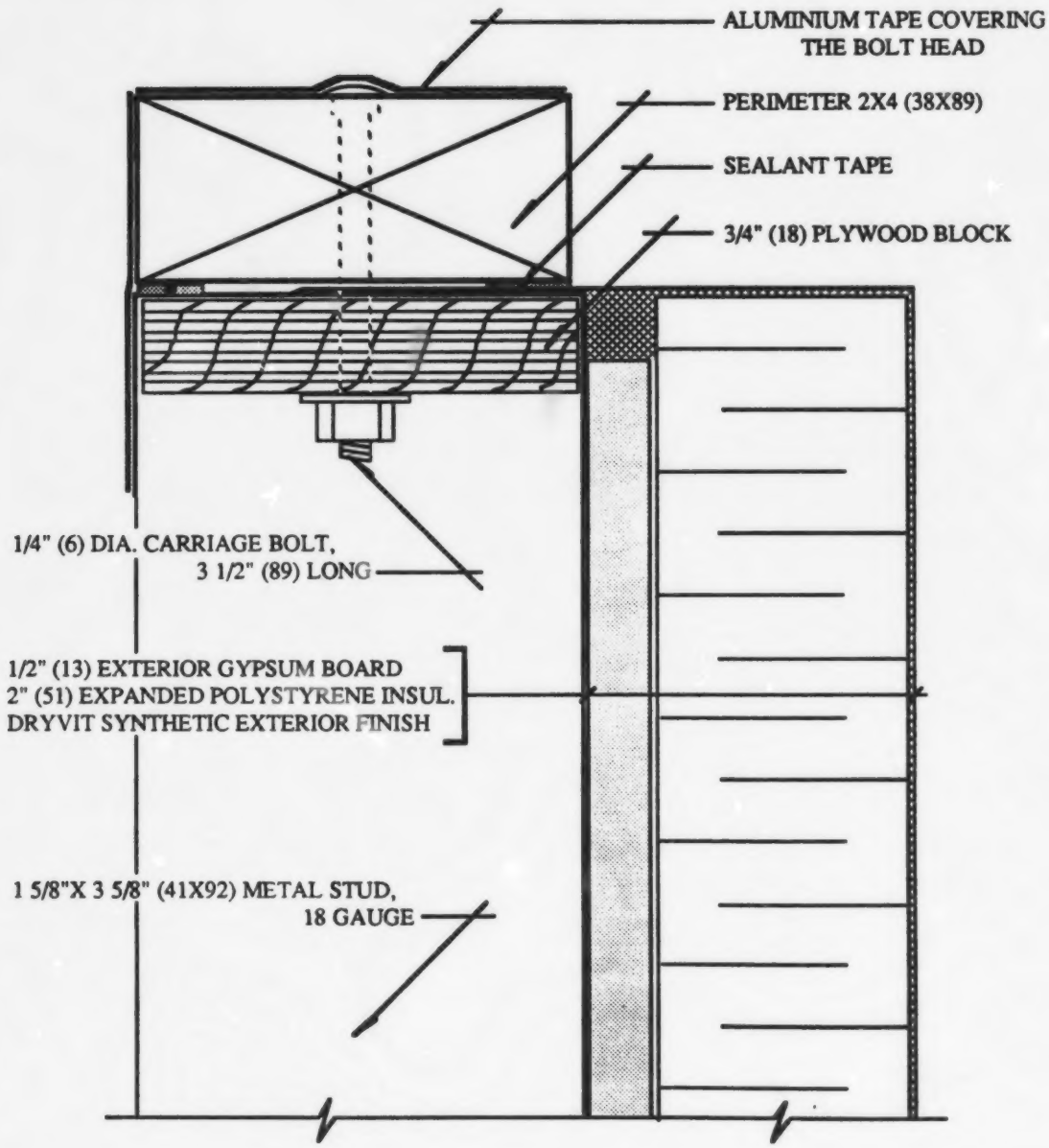
Test specimen # 6 consisted of a prefabricated wall panel made of a steel stud structure, exterior gypsum board, expanded polystyrene insulation and a synthetic exterior finish. The test specimen was supplied by Dryvit System Inc.. In such a system, the construction of the gypsum board, the insulation and the synthetic finish were considered as one unit which provides the structural requirements of the air barrier system. The synthetic exterior finish was considered as the air tightness component of the air barrier assembly. The air tightness line was carried to the test box by compressing a sealant tape between the perimeter 2X4's (38X89) and the synthetic finish along the side of the steel studs located at the perimeter of the test specimen (see " DETAIL B "). The sealant tape with a black circle in the centre in " DETAIL B " was installed as a leveller to keep the side of the perimeter 2X4's (38X89) parallel to the side of the steel stud. The perimeter 2X4's (38X89) were anchored to the steel stud structure with carriage bolts. The heads of all these anchorage bolts were covered with an aluminium tape. The corners of the perimeter 2X4's (38X89) were sealed with sealant tape and covered with an aluminium tape.



SIDE VIEW


8'- 4 1/2"
2553
8'- 1 1/2"
2477
B
GYPSUM BOARD
OUTLINE
DRYVIT TEST SPECIMEN
PERIMETER 2X4'S (38X89)
8'- 1 1/2"
2477
8'- 4 1/2"
2553

FRONT VIEW


ALUMINIUM TAPE COVERING
THE BOLT HEAD
PERIMETER 2X4 (38X89)
SEALANT TAPE
3/4" (18) PLYWOOD BLOCK
1/4" (6) DIA. CARRIAGE BOLT,
3 1/2" (89) LONG
1/2" (13) EXTERIOR GYPSUM BOARD
2" (51) EXPANDED POLYSTYRENE INSUL.
DRYVIT SYNTHETIC EXTERIOR FINISH
1 5/8"X 3 5/8" (41X92) METAL STUD,
18 GAUGE

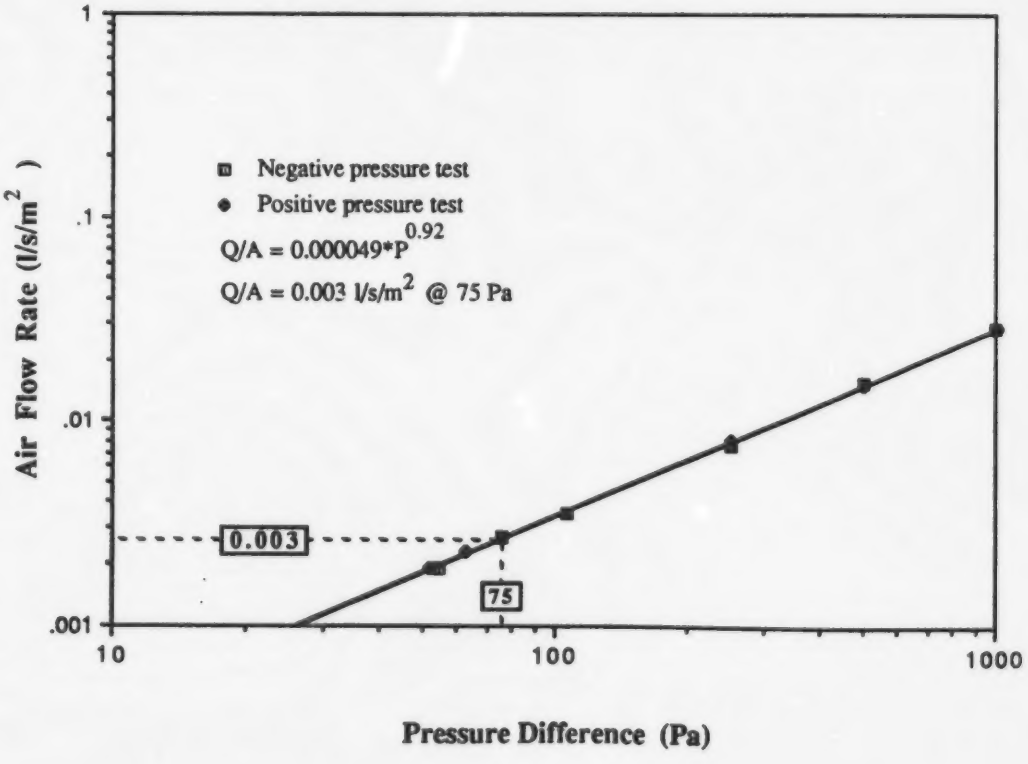
DETAIL B

As Built Details:

i) Test specimen # 6 was tested as supplied by the manufacturer.

ii) The construction details given were obtained by cutting sections of the test specimen.

B) Air Leakage Rate Tests



C) Structural Performance Tests

i) Sustained Load Tests

(The test period of the sustained load tests was one hour)

Test Pressure (Pa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-250	-76	0.003	0.003
-500	-76	0.003	0.003
-1000	-76	0.003	0.003
+250	+75	0.003	0.003
+500	+76	0.003	0.003
+1000	+76	0.003	0.003

ii) Gust Load Tests

(The test period of the gust load tests was in the range of 5 to 10 seconds)

Test Pressure (kPa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-1.5	-76	0.003	0.003
-2.0	-76	0.003	0.003
-2.5	-76	0.003	0.003
+1.5	+76	0.003	0.003
+2.0	+76	0.003	0.003
+2.5	+76	0.003	0.003

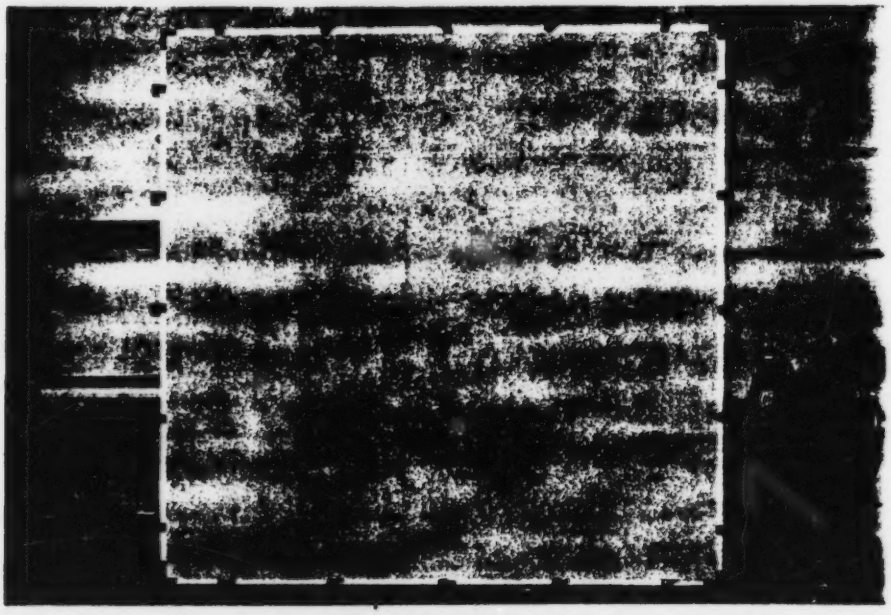
D) Observations And Comments

The air leakage tests indicated an air leakage rate of 0.003 l/s/m^2 at 75 Pa for test specimen # 6. This value is approximately thirty three times smaller than the value suggested during the Building Science Insight'86 for moderate inside climate of 0.10 l/s/m^2 at a pressure difference of 75 Pa. The air leakage verification tests carried out after each of the structural tests indicated no change in the air leakage rate of the assembly (see Section C).

The air barrier system performed structurally through all the sustained load and gust load tests. During the visual inspections carried out after each structural tests and at the removal of the test specimen from the test box no physical change of the components of the assembly was observed.

Test specimen # 6 air barrier system is very air tight and performed structurally through all the specified structural tests. The gypsum board layer of the prefabricated wall panel tested was somewhat unusual in that it was made of gypsum board pieces of different sizes (see " FRONT VIEW "). The gypsum boards were screwed to the steel stud structure approximately every 4 (102) to 5 (127) inches along the edges and 4 (102) to 6 (152) inches along the intermediate supports. Since the attachment of the air barrier system to the supporting structure plays a major roll in the structural performance of the system, the use of full size gypsum boards might lead to a different performance then the one obtained for test specimen # 6.

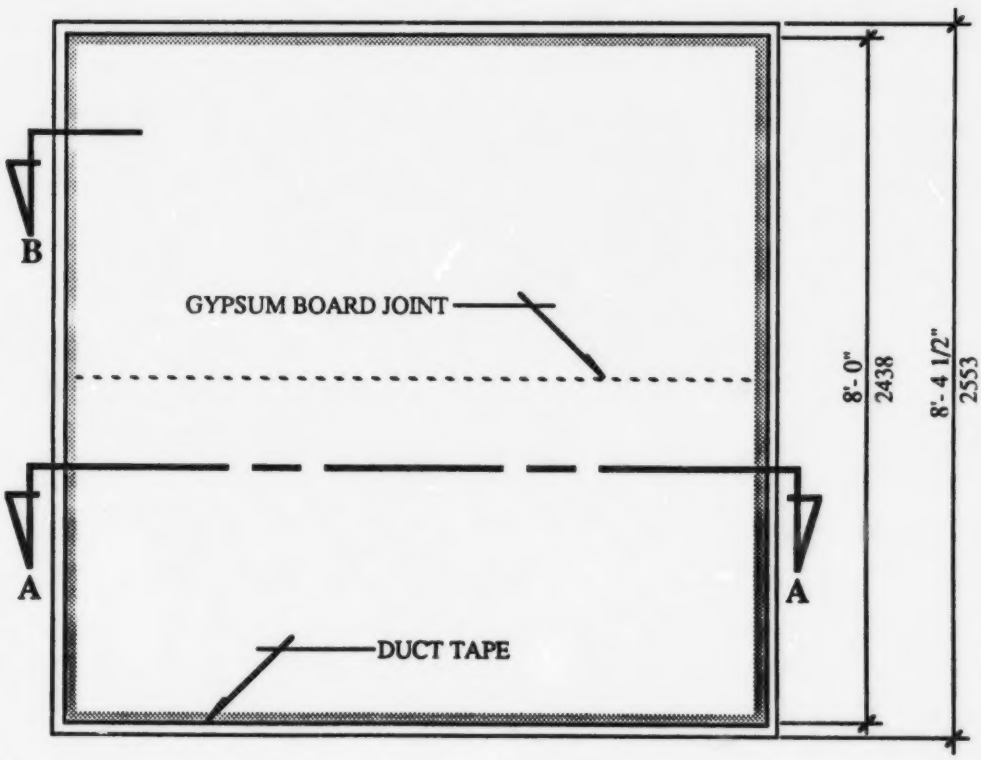
Photo 6-1:



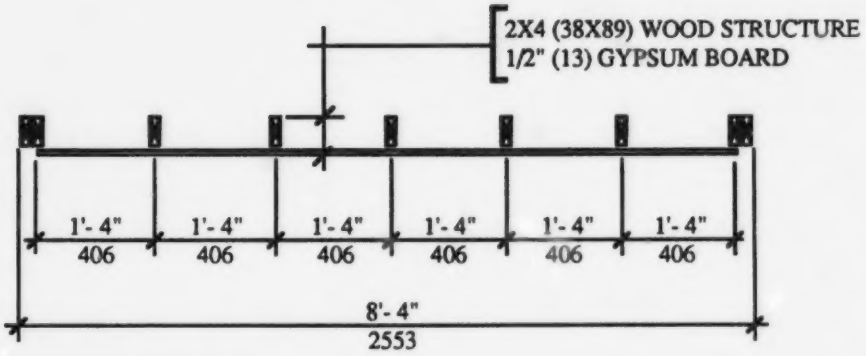
Test Specimen #7

A) Description

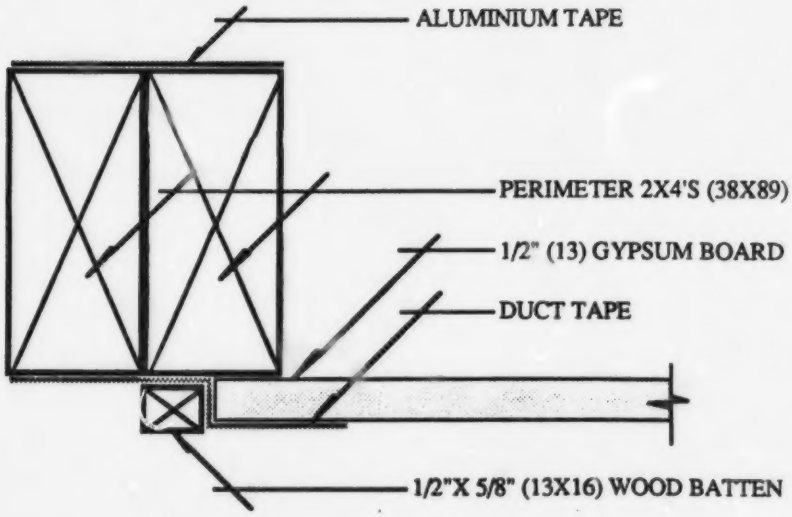
Test specimen # 7 consisted of gypsum boards , drywall joint compound and paper tape. In such a design, the gypsum boards provide both the air tightness and the structural requirements in the air barrier system and the drywall joint compound and paper tape provide the air tightness continuity between gypsum boards and at the screw perforations. The air tightness line of the air barrier system was carried to the test box by taping the perimeter of the assembly to the perimeter 2X4's (38X89) with duct tape. A wood batten was used to provide structural support to the tape along the air barrier assembly (see " DETAIL B ").



FRONT VIEW



SECTION AA



DETAIL B

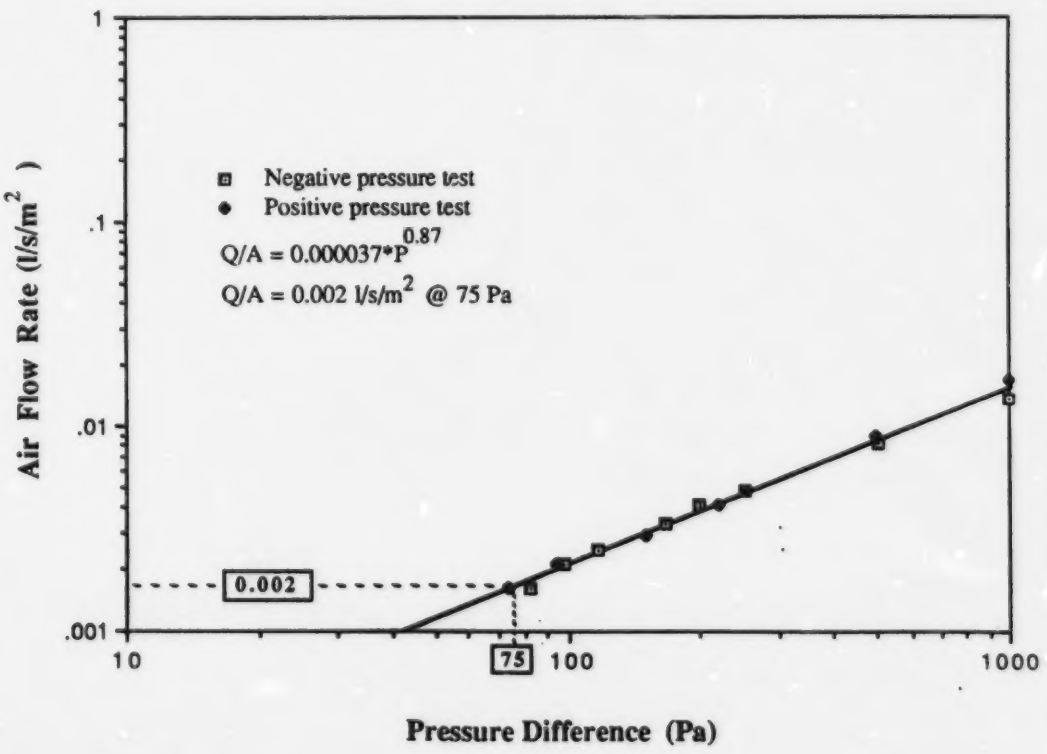
As Built Details:

i) The 1/2" (13) gypsum boards were attached horizontally to the wood structure with 1 1/4" (32) drywall screws at 8" (203) o.c. along the edge supports and at 12" (305) o.c. along the intermediate supports.

ii) The horizontal joint was sealed with two coats of drywall joint compound and paper tape. The screw heads were sealed with two coats of drywall joint compound.

iii) The drywall surface was painted with two coats of latex paint.

B) Air Leakage Rate Tests



C) Structural Performance Tests

i) Sustained Load Tests

(The test period of the sustained load tests was one hour)

Test Pressure (Pa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-250	-76	0.002	0.002
-500	-81	0.002	0.002
-1000	-79	0.002	0.002
+250	+74	0.002	0.002
+500	+74	0.002	0.002
+1000	+75	0.002	0.002

ii) Gust Load Tests

(The test period of the gust load tests was in the range of 5 to 10 seconds)

Test Pressure (kPa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-1.5	-86	0.002	0.002
-2.0	-76	0.002	0.002
-2.5	-84	0.002	0.002
+1.5	+79	0.002	0.002
+2.0	+79	0.006	0.002
+2.5	The air barrier system failed structurally at approximately +1.8 kPa.		

D) Observations And Comments

The air leakage tests indicated an air leakage rate of 0.002 l/s/m^2 at 75 Pa for test specimen # 7. This value is approximately fifty times smaller than the value suggested during the Building Science Insight'86 for moderate inside climate of 0.10 l/s/m^2 at a pressure difference of 75 Pa. The air leakage verification tests carried out after each of the structural tests, performed before the +2.0 kPa gust load test, indicated no change in the air leakage rate of the assembly (see Section C). After the +2.0 kPa gust load test the air leakage rate increased to 0.006 l/s/m^2. The +2.5 kPa gust load test was not performed because of a complete structural failure of the system during a second +2.0 kPa test.

The air barrier system performed structurally through all the sustained load and gust load tests under negative pressure difference. That is, the air leakage rate did not change and no physical failure of the components of the asssembly was observed. Under positive pressure differences the system failed structurally during the 2.0 kPa gust load test. At a pressure difference of +1.8 kPa the lower gypsum board pulled off from all the screws along the intermediate supports and three short cracks were observed at the gypsum board horizontal joint. (The locations of the cracks are marked with solid line loops on " Photo 7-1 ".) The structural failure did not cause a complete break of the air seal at all screw locations since the joint compound covering the screw heads was broken at only a few locations and the screw head was still providing some air tightness. Since the air leakage rate of the assembly was still low (0.006 l/s/m^2) after this test, it was decided to repeat the +2.0 kPa gust load test to obtain additional information on the structural performance of test specimen # 7. On the second attempt at the +2.0 kPa test, the top gypsum board pulled off from the screws along the intermediate supports at a pressure difference of approximately +1.6 kPa. During this structural failure the gypsum board joint broke along the whole length and the gypsum boards were pushed off several screws (see Photos 7-2 and 7-3). The air leakage verification test was not performed after this test because a complete structural failure of the system had occurred.

Test specimen # 7 air barrier system is very air tight but its attachment to the supporting structure requires more attention. The double fastening technique is a possible answer to the assembly attachment weakness. With a slight modification in its fixation to the supporting structure, test specimen # 7 might have performed structurally through the specified structural tests.

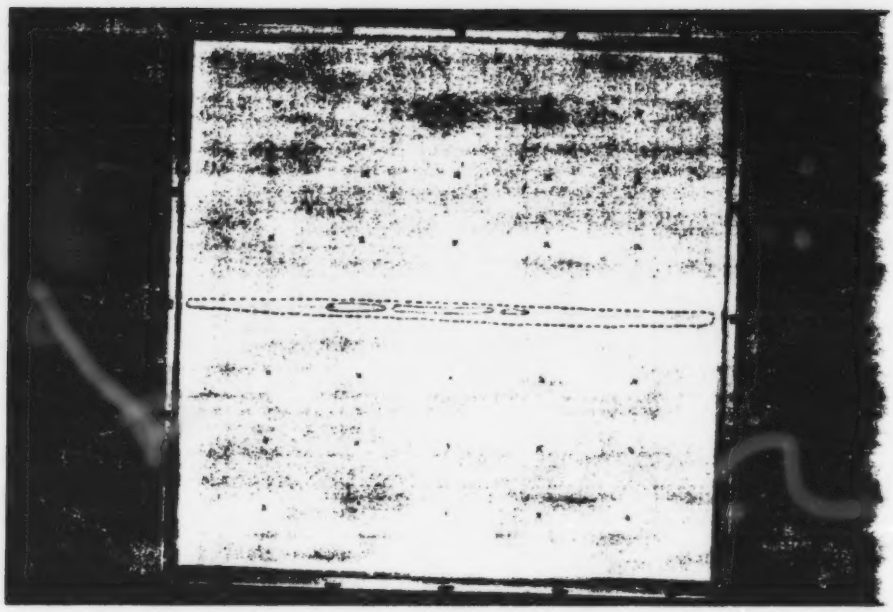


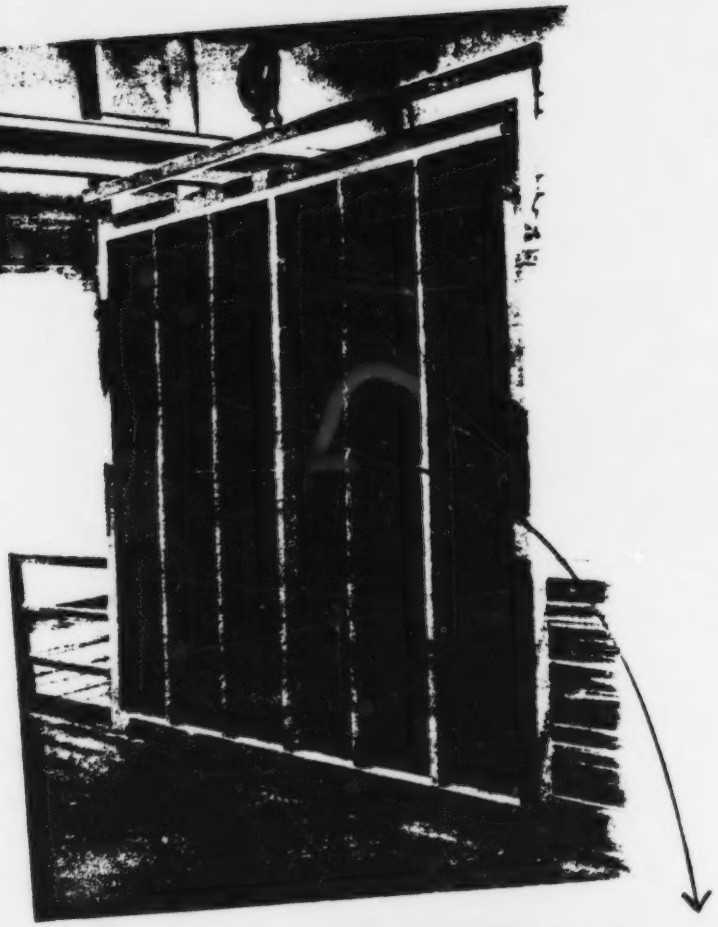
Photo 7-1:

- The Xs indicate the locations of the screws along the intermediate supports in the surface of the gypsum boards.

- The solid line loops indicate where the gypsum board joint broke on the first failure.

- The broken line loop indicates where the gypsum board joint broke on the second failure.

Photo 7-2



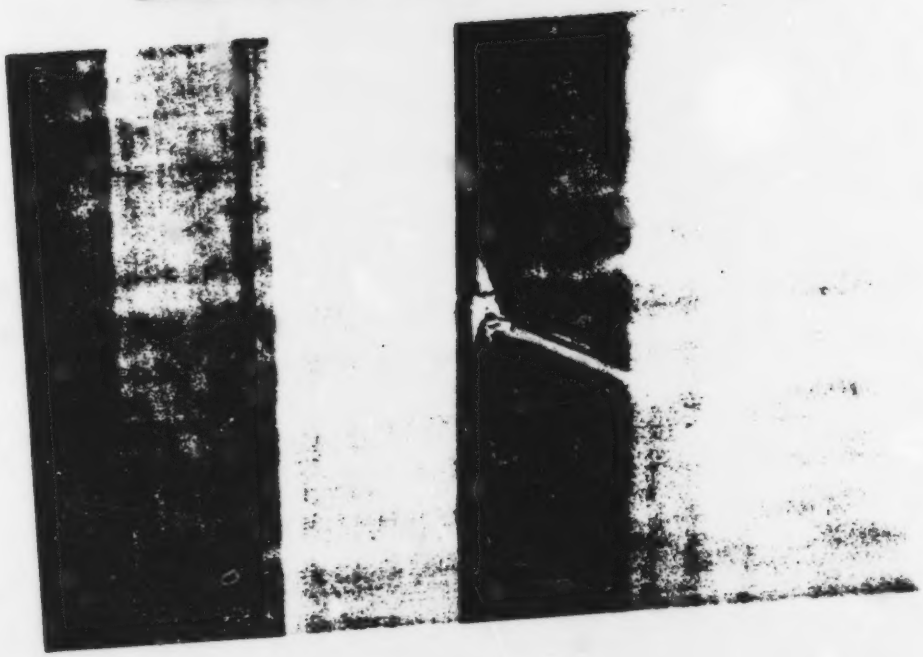
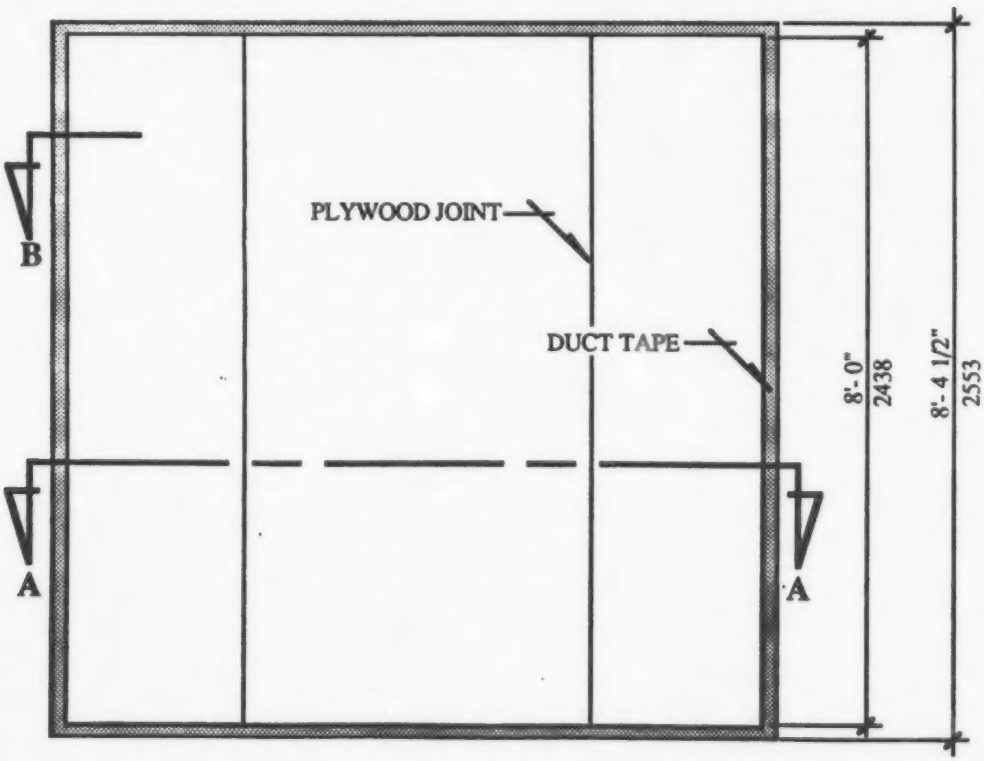


Photo 7-3

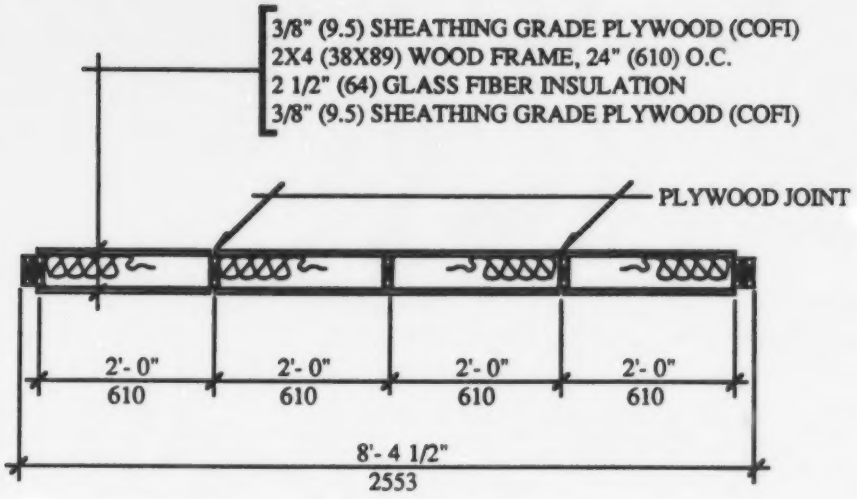
Test Specimen #8

A) Description

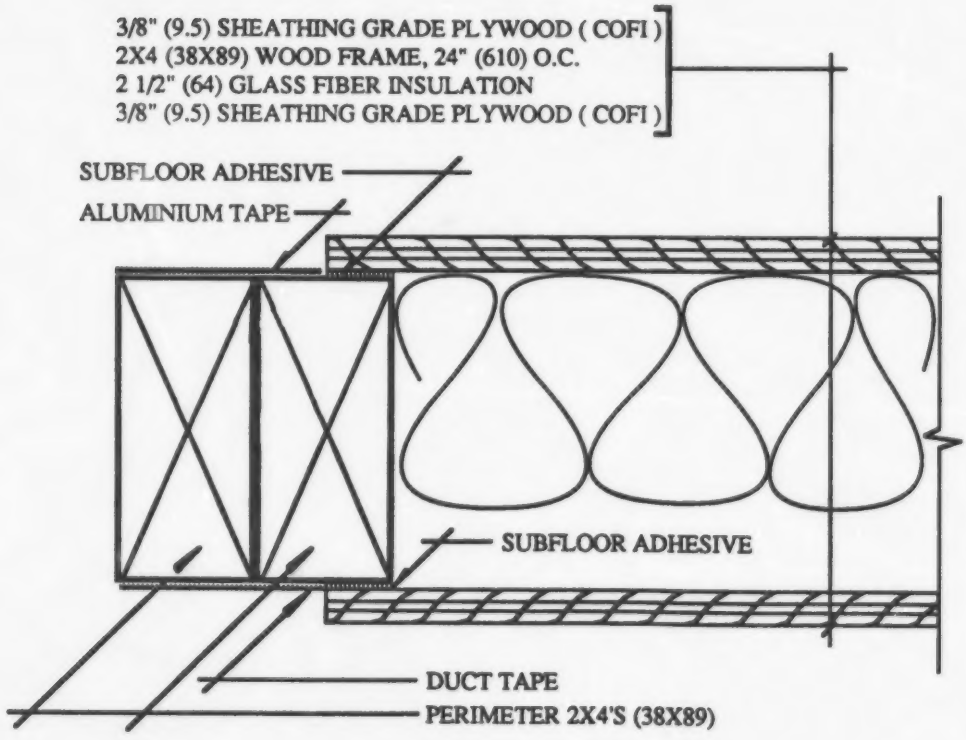
Test specimen # 8 was a wall panel consisting of a wood frame covered on both sides by a plywood skin. In such a system the construction of the wood frame and the plywood sheathing provides both the structural and air tightness requirements of the air barrier system. The air tightness continuity is insured within the assembly by gluing the plywood sheathing to the 2X4 (38X89) studs. Since both plywood skins are presumedly providing the same resistance to through air flow, the air tightness line was carried to the test box from each plywood skin by taping both edges of the perimeter 2X4's (38X89) (see " DETAIL B"). Both edges were taped only to the edge of the plywood skin because the glue is providing the air tightness continuity between the plywood sheathing and the wood structure. The edge of the perimeter 2X4's (38X89) making contact with the test box gasket was taped with aluminium tape as it was done for all the test specimen. The outer edge of the perimeter 2X4's (38X89) was taped with duct tape to make a visual distinction between the two sides.



FRONT VIEW



SECTION AA


3/8" (9.5) SHEATHING GRADE PLYWOOD (COFI)
2X4 (38X89) WOOD FRAME, 24" (610) O.C.
2 1/2" (64) GLASS FIBER INSULATION
3/8" (9.5) SHEATHING GRADE PLYWOOD (COFI)
SUBFLOOR ADHESIVE
ALUMINIUM TAPE
SUBFLOOR ADHESIVE
DUCT TAPE
PERIMETER 2X4'S (38X89)

DETAIL B

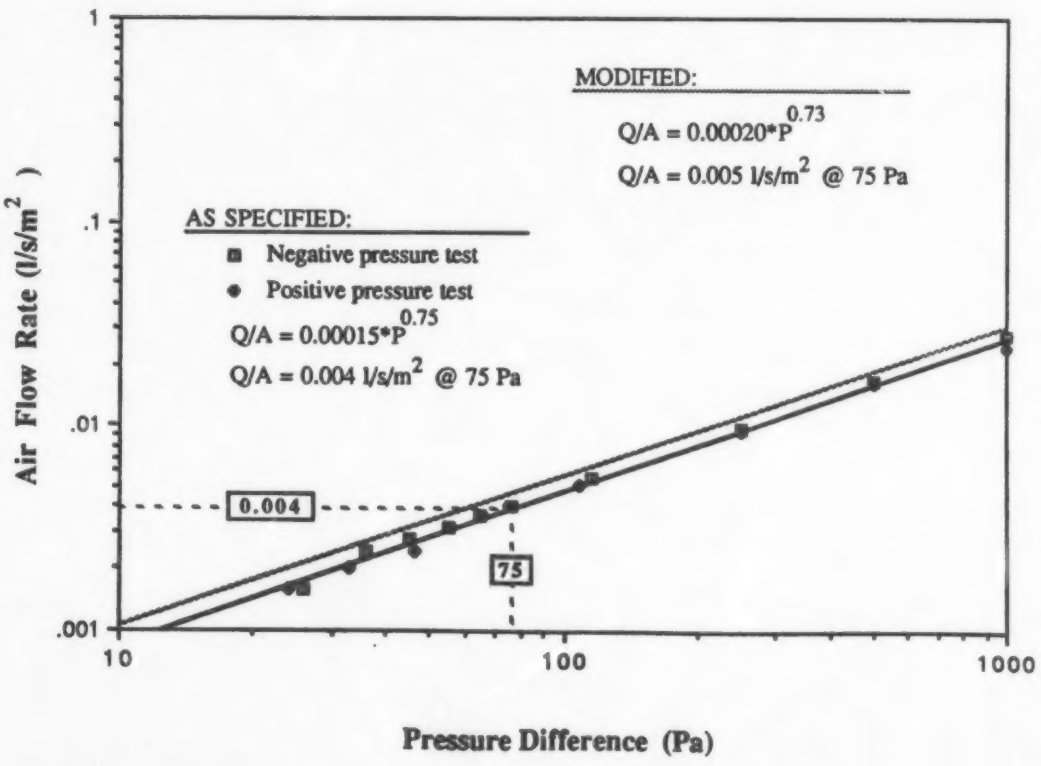
As Built Details:

i) The frame of the wall panel was made of 2X4 (38X89) studs spaced at 24" (610) o.c. with a single top and bottom plate.

ii) Both plywood skins were glued to all studs and plates with subfloor adhesive (see Photo 8-1). The plywood sheathing was also attached to all framing members with 1 1/4" (32) drywall screws at 6" (152) o.c..

iii) As requested by the proponent, 2 1/2" (64) glass fiber batt insulation was installed in the cavities against the inner plywood skin, leaving a 1" (25) air space between the insulation and the outer plywood skin.

B) Air Leakage Rate Tests



C) Structural Performance Tests

i) Sustained Load Tests

(The test period of the sustained load tests was one hour)

Test Pressure (Pa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-250	-76	0.004	0.004
-500	-76	0.004	0.004
-1000	-76	0.004	0.004
+250	+76	0.004	0.004
+500	+75	0.004	0.004
+1000	+76	0.004	0.004

ii) Gust Load Tests

(The test period of the gust load tests was in the range of 5 to 10 seconds)

Test Pressure (kPa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-1.5	-76	0.004	0.004
-2.0	-76	0.004	0.004
-2.5	-76	0.004	0.004
+1.5	+75	0.004	0.004
+2.0	+75	0.004	0.004
+2.5	+76	0.004	0.004

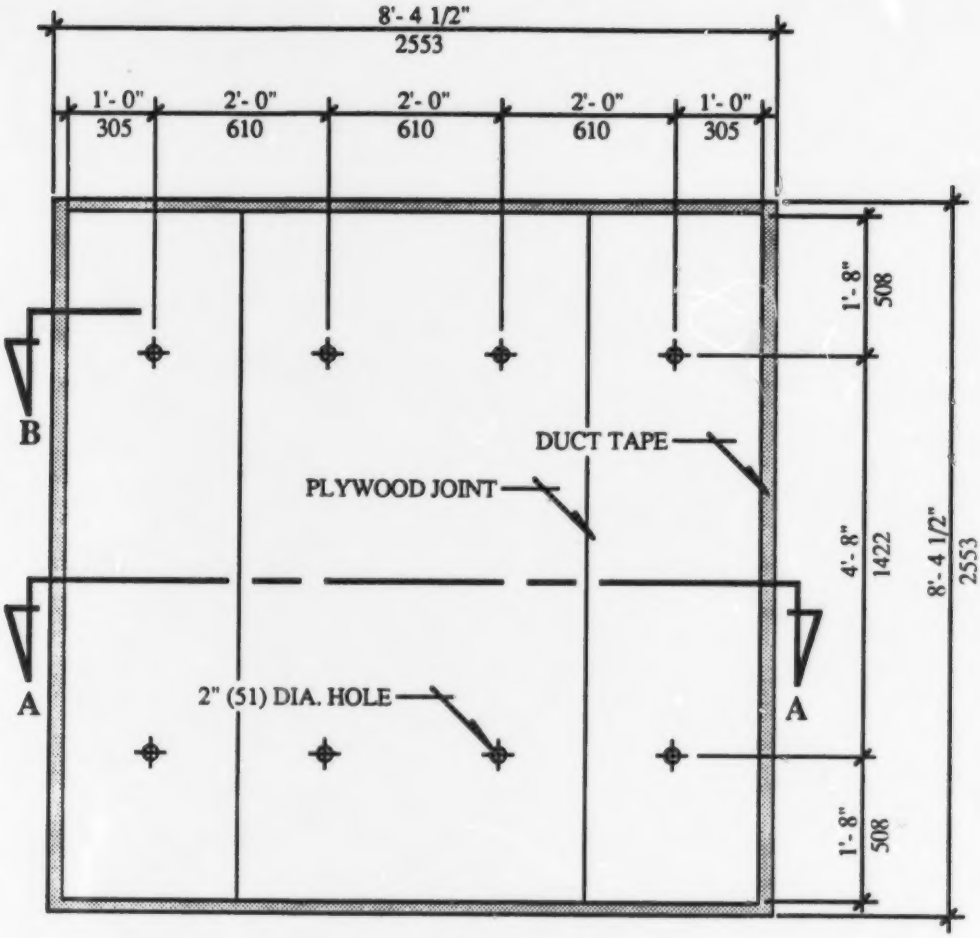
D) Observations And Comments

The air leakage tests indicated an air leakage rate of 0.004 l/s/m^2 at 75 Pa for test specimen # 8. This value is approximately twenty five times smaller than the value suggested during the Building Science Insight'86 for moderate inside climate of 0.10 l/s/m^2 at a pressure difference of 75 Pa. The air leakage verification tests carried out after each of the structural tests indicated no change in the air leakage rate of the assembly (see Section C).

The air barrier system performed structurally through all the sustained load and gust load tests. That is, the air leakage rate did not change and no physical failure of the components of the asssembly was observed[1] .

Test specimen # 8 air barrier system is very air tight and performed very well through the specified structural tests. However, one could question the need of two air tight plywood skins in such an air barrier system design. A single plywood skin with the same attachment technique to the wood structure could probably perform just as well. In that context, before removing the test specimen from the test box, test specimen # 8 was modified to a single plywood skin system by drilling 2" (51) diameter holes in the exposed plywood skin at the top and bottom of each stud space (see schematic and Photo 8–2 below for modified test specimen). An air leakage test was then performed from approximately 10 Pa to 500 Pa for both positive and negative pressure differences. The 1000 Pa sustained load test and the 2.5 kPa gust load test were also repeated for both positive and negative pressure differences. The air leakage tests indicated an air leakage rate of 0.005 l/s/m^2 at a pressure difference of 75 Pa (see "MODIFIED" in Section B). The air leakage verification tests after each structural test indicated identical air leakage rates. When the test specimen was removed from the test box no structural failure of the inside plywood skin was observed.

[1] The visual inspection after each structural test was limited to the exterior plywood skin because of the test sample and the test box configuration.



FRONT VIEW - MODIFIED SPECIMEN

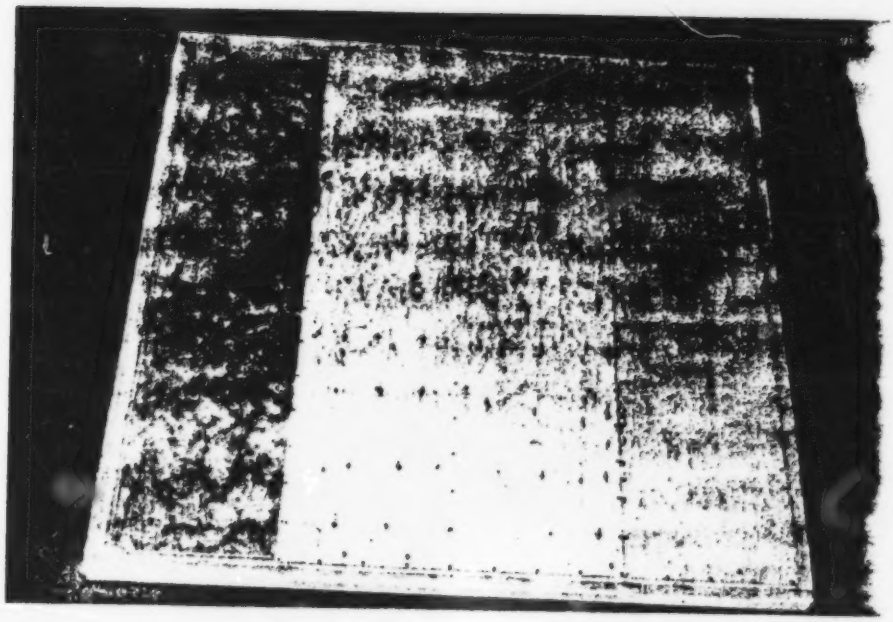


Photo 8-1:

Construction of test specimen # 8

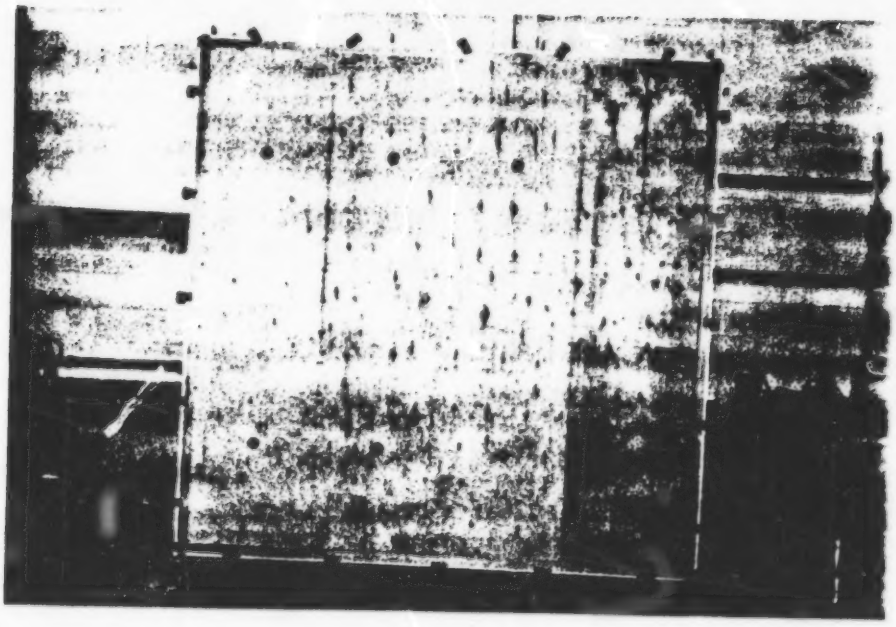


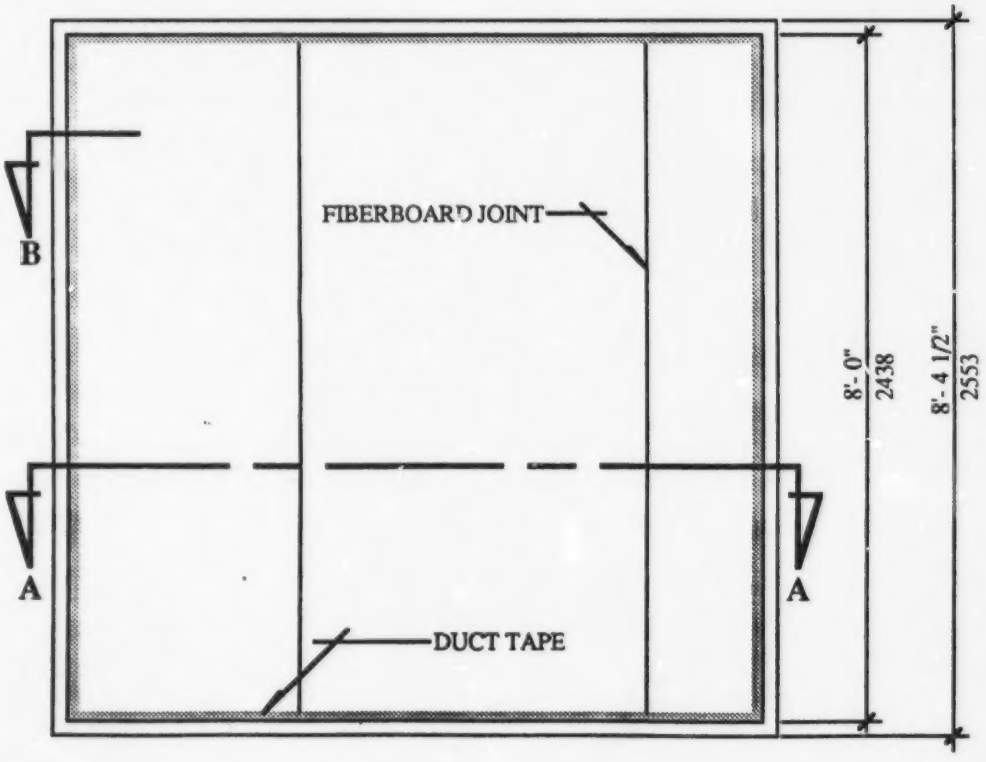
Photo 8-2:

Modified test specimen # 8

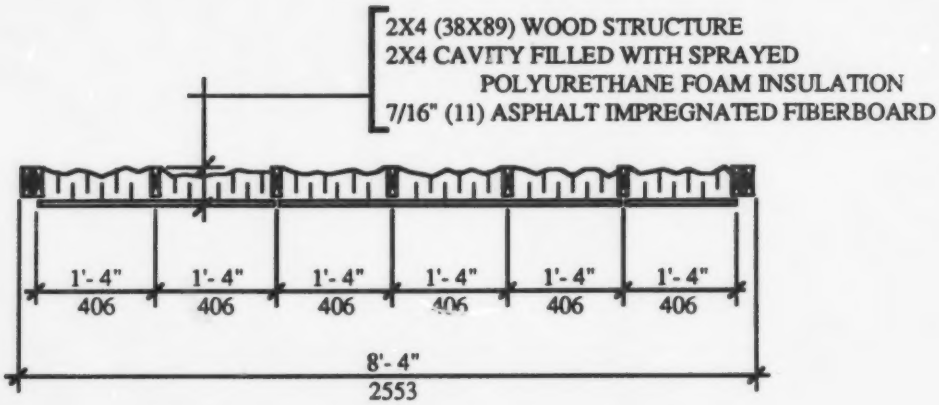
Test Specimen #9

A) Description

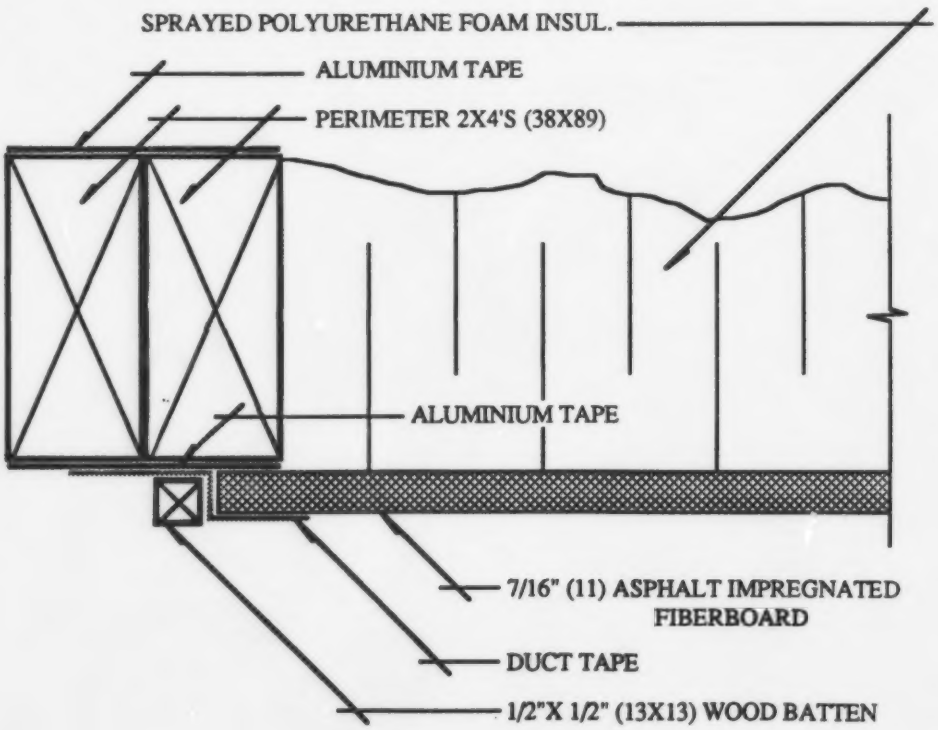
Test specimen # 9 air barrier system consisted of a 2X4 (38X89) stud frame covered with asphalt impregnated fiberboards on one side and polyurethane foam insulation in the stud cavities. In such a system, the construction of the wood frame, the fiberboards, and the insulation provides both the air tightness and structural requirements of the air barrier system. The air tightness of the system was carried to the test box by taping the edges of the perimeter 2X4's (38X89) edges with aluminium tape and the perimeter of the fiberboard surface to the perimeter 2X4's (38X89) with duct tape (see " DETAIL B "). A wood batten was used to provide structural support to the duct tape.



FRONT VIEW



SECTION AA



DETAIL B

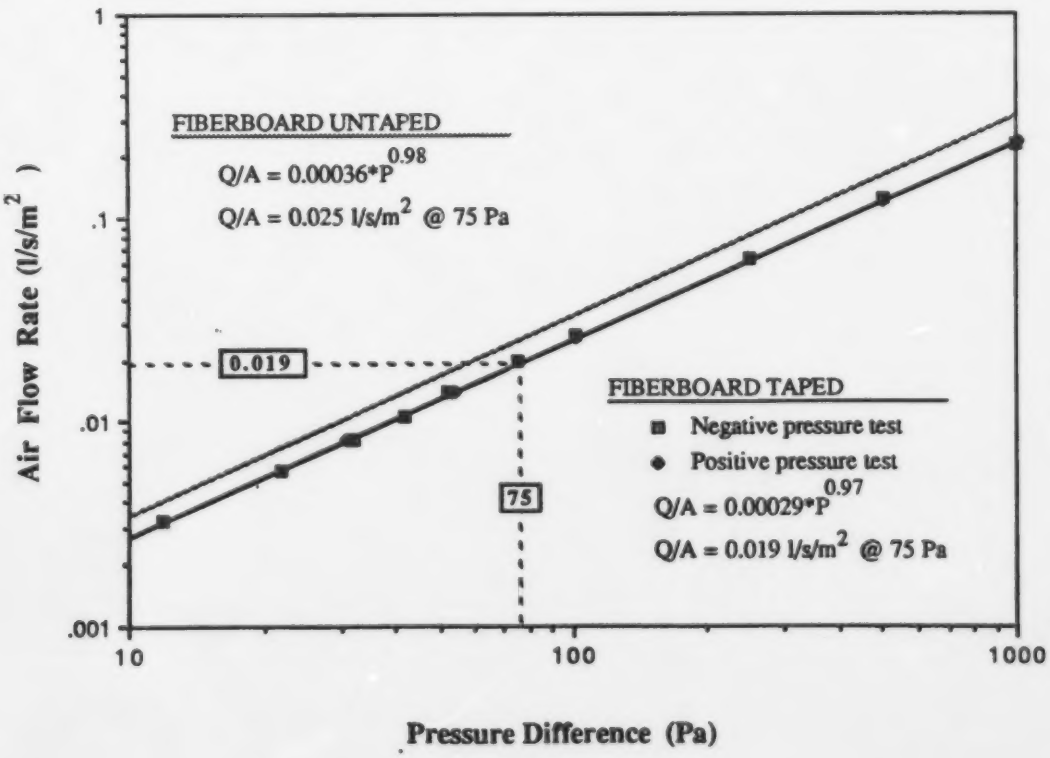
As Built Details:

i) The 7/16" (11) asphalt impregnated fiberboards were nailed to the wood structure with 1 3/4" (45) galvanized roofing nails at 6" o.c. along the edges and at 12" o.c. along the intermediate supports.

ii) The 2X4 (38X89) stud cavities were filled with at least 3" (76) thick of standard density (37 kg/m^3) spray applied polyurethane foam insulation. The insulation was sprayed in place by a professional foam applicator.

iii) Polyurethane foam insulation in excess of 3 1/2" (89) was cut flush to the face of the 2X4's (38X89).

B) Air Leakage Rate Tests



C) Structural Performance Tests

i) Sustained Load Tests

(The test period of the sustained load tests was one hour)

Test Pressure (Pa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-250	-76	0.020	0.019
-500	-76	0.019	0.019
-1000	-76	0.020	0.019
+250	+76	0.019	0.019
+500	+76	0.020	0.019
+1000	+76	0.019	0.019

ii) Gust Load Tests

(The test period of the gust load tests was in the range of 5 to 10 seconds)

Test Pressure (kPa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-1.5	-75	0.019	0.019
-2.0	-75	0.019	0.019
-2.5	-75	0.019	0.019
+1.5	+76	0.019	0.019
+2.0	+76	0.019	0.019
+2.5	+75	0.019	0.019

D) Observations And Comments

The air leakage tests indicated an air leakage rate of 0.019 l/s/m^2 at 75 Pa for test specimen # 9. This value is approximately five times smaller than the value suggested during the Building Science Insight'86 for moderate inside climate of 0.10 l/s/m^2 at a pressure difference of 75 Pa. The air leakage verification tests carried out after each of the structural tests indicated no change in the air leakage rate of the assembly (see Section C).

The air barrier system performed structurally through all the sustained load and gust load tests. The air leakage rate did not change and no significant physical change of the components of the assembly was observed during the visual inspections. During the +500 Pa sustained load test several nail heads became partially embedded in the fiberboard (see Photo 9-1). However, the indentations were not deep and did not increase during the subsequent tests. This physical change of the fiberboard did not cause the air leakage rate of the assembly to increase. Consequently, it was not considered as a structural failure.

After the structural tests, the duct tape along the perimeter of the fiberboard was removed and an air leakage test was performed from approximately 10 Pa to 1000 Pa for both positive and negative pressure differences . The air leakage tests indicated an air leakage rate of 0.025 l/s/m^2 at a pressure difference of 75 Pa (see " FIBERBOARD UNTAPED " in Section B). This value is four times smaller than the value suggested during the Building Science Insight'86 for moderate inside climate at a pressure difference of 75 Pa. These two air leakage tests were performed to see how the air leakage rate of the system will vary if the perimeter edges of the fiberboard were not sealed. In practice the fiberboard edges will most likely not be sealed. In such a system, one concern is the air tightness continuity of the system at the double top plate and between the polyurethane foam insulation and the stud frame. If the fiberboard was not well seated on top of the framing member to form a seal and a significant crack existed between the two plates, an air leakage problem could occur. A similar problem can occur if the bond between the insulation and the stud frame was poor. When the edges of the fiberboard are sealed some addtional air tightness is provided.

In the cleaning process of the polyurethane foam insulation, several locations were found where the insulation was not bonded to the side of the stud. These locations were marked and examined for changes after the full series of tests (see Photo 9-2). No changes were observed.

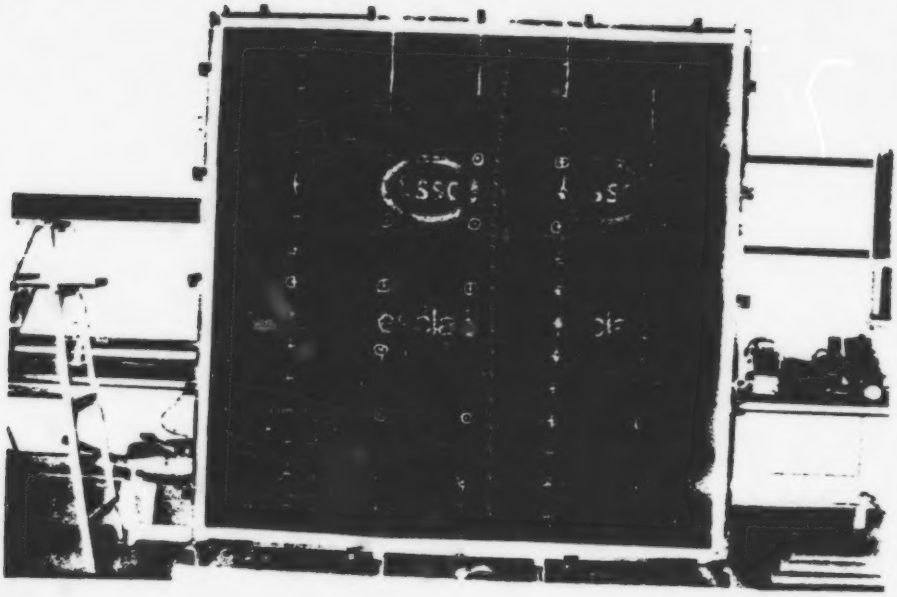


Photo 9-1:

Circles indicate where nail heads became partially embedded in fiberboard.

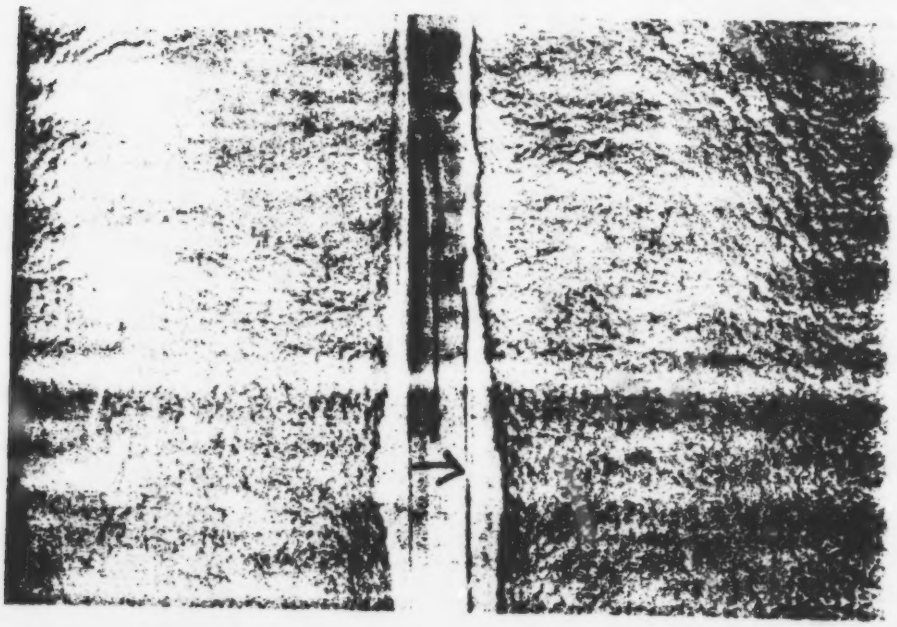


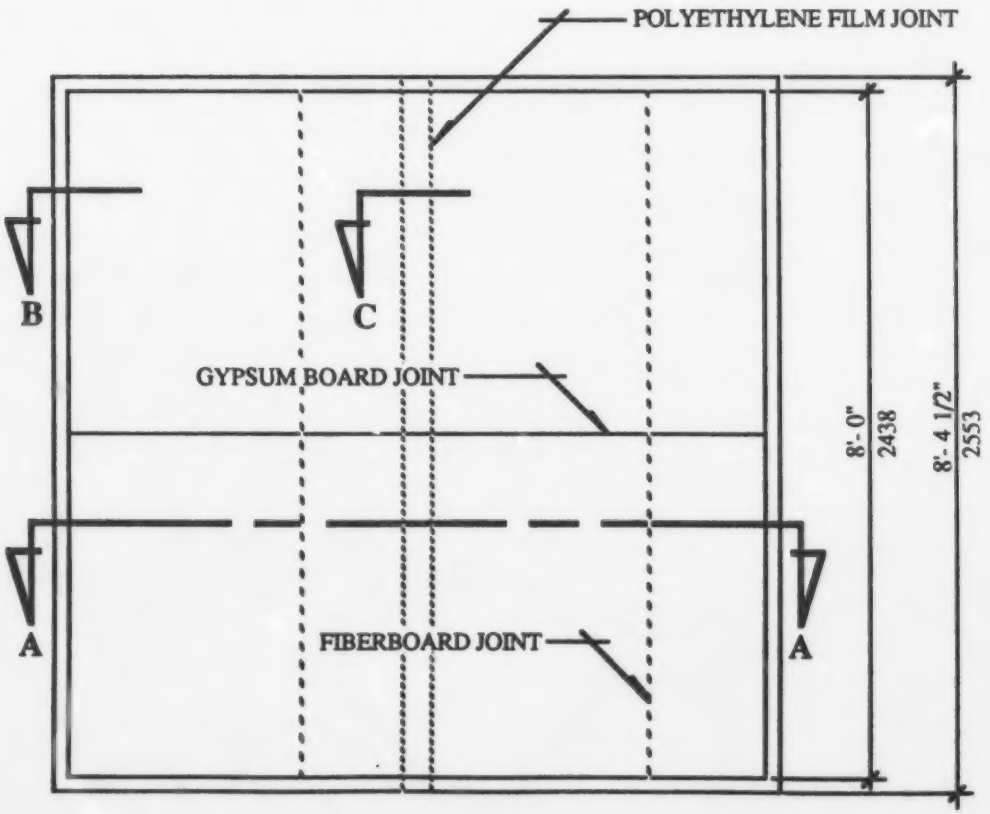
Photo 9-2:

Lack of bond between the polyurethane foam insulation and wood stud.

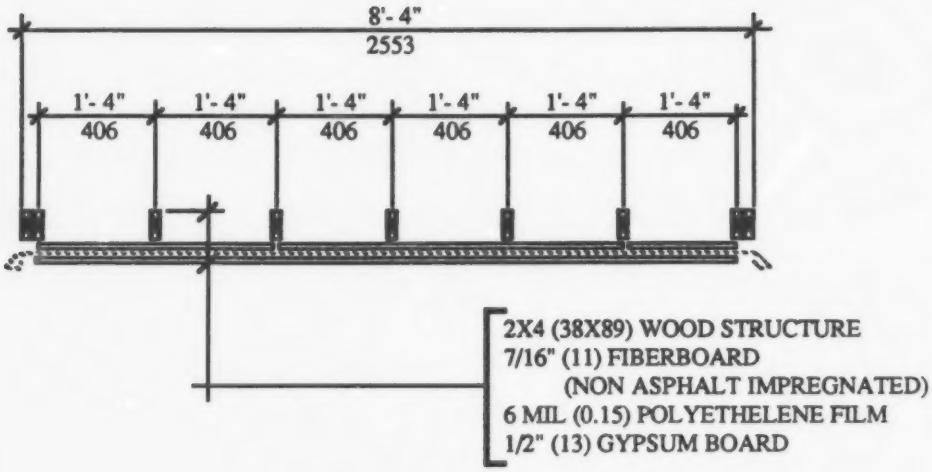
Test Specimen #10

A) Description

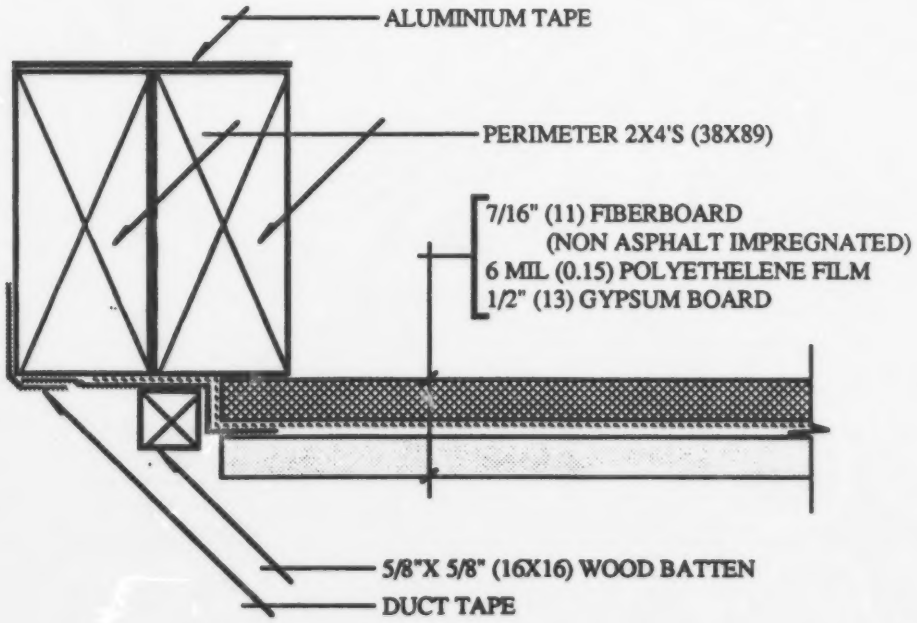
Test specimen # 10 was a three component air barrier system consisting of a fiberboard, a polyethelene film and gypsum board. In such a system, the fiberboard and the gypsum board are structural components and the polyethelene film is the air tightness component. The air tightness line was carried to the test box by taping the polyethelene film to the perimeter 2X4's (38X89) with duct tape (see " DETAIL B "). The tape was installed before the installation of the gypsum boards. The duct tape was extended to the polyethelene surface between the perimeter of the fiberboard and gypsum board to obtain the best seal possible because of the wrinkle produced in the polyethelene film when folded over the edge of the fiberboard. A wood batten was used to provide structural support to the duct tape.



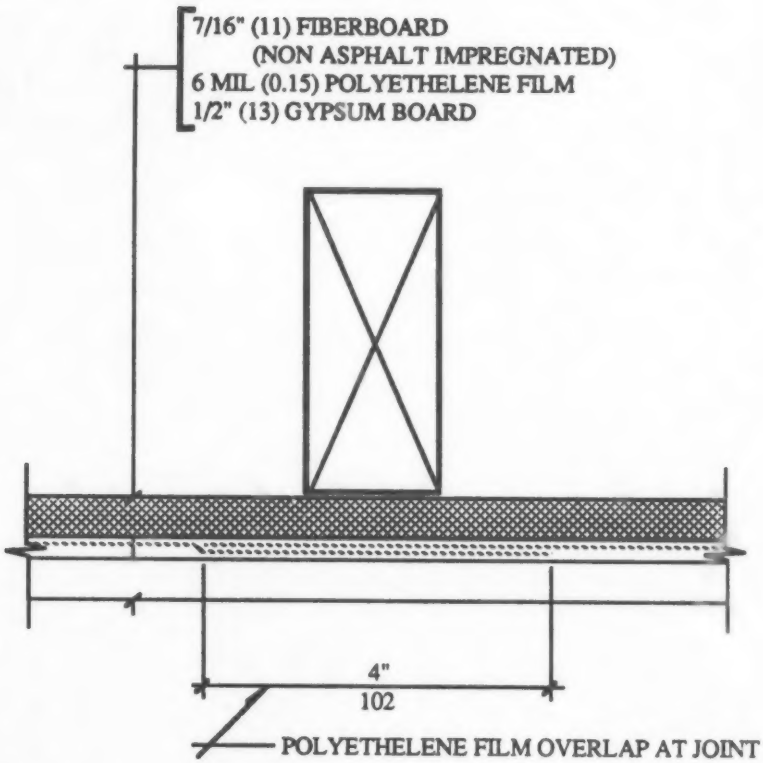
FRONT VIEW



SECTION AA



DETAIL B


7/16" (11) FIBERBOARD
(NON ASPHALT IMPREGNATED)
6 MIL (0.15) POLYETHELENE FILM
1/2" (13) GYPSUM BOARD
4"
102
POLYETHELENE FILM OVERLAP AT JOINT

DETAIL C

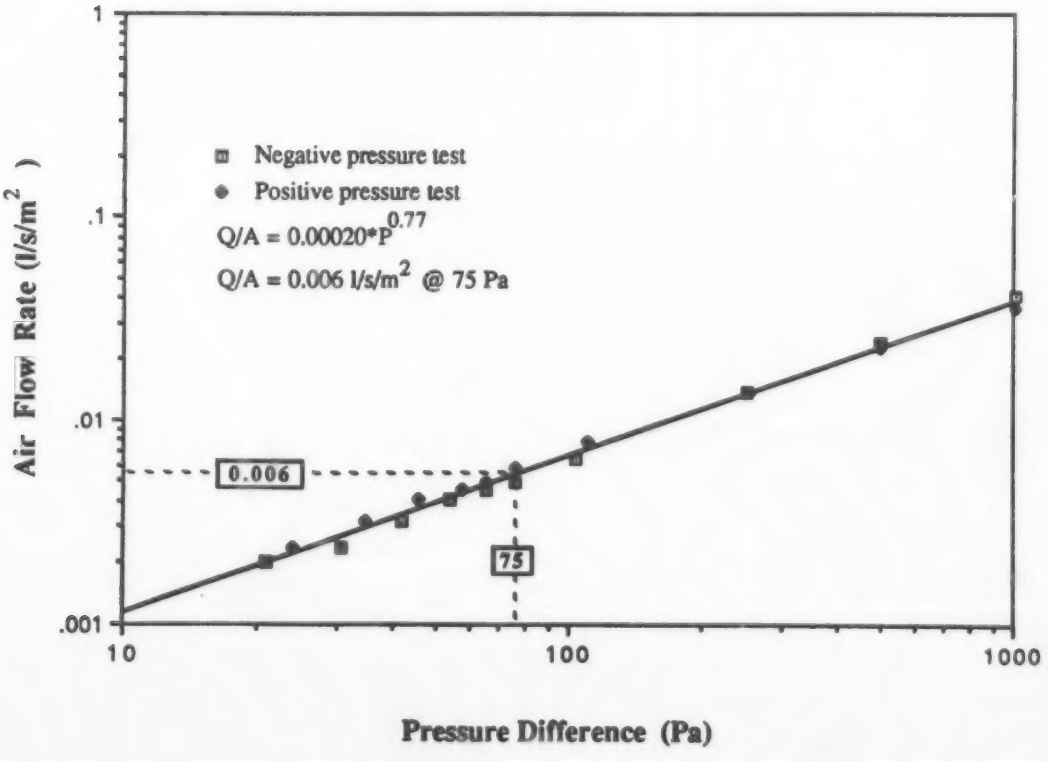
As Built Details:

i) The 7/16" (11) fiberboards, non asphalt impregnated, were installed vertically to the 2X4 (38X89) structure with 1 3/4" (45) galvanized roofing nails every 4" (102) along edges and every 8" (203) along the intermediate supports.

ii) The 6 mil (0.15) polyethelene film was installed with a 4" (102) overlap at the center of the test specimen and stapled to the fiberboard with 1/4" (6) staples every 2'-0" (610) for temporary support.

iii) The 1/2" (13) gypsum boards were installed horizontally to the wood structure, on top of the polyethelene film, with 2" (51) drywall screws every 8" (203) along the edges and every 12" (305) along the intermediate supports. The gypsum board joint was not sealed.

B) Air Leakage Rate Tests



C) Structural Performance Tests

i) Sustained Load Tests

(The test period of the sustained load tests was one hour)

Test Pressure (Pa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-250	-76	0.005	0.006
-500	-76	0.005	0.006
-1000	-76	0.005	0.006
+250	+76	0.006	0.006
+500	+76	0.006	0.006
+1000	+75	0.006	0.006

ii) Gust Load Tests

(The test period of the gust load tests was in the range of 5 to 10 seconds)

Test Pressure (kPa)	Verification Pressure (Pa)	Verification Air Flow Rate ($l/s/m^2$)	Calculated Air Flow Rate ($l/s/m^2$)
-1.5	-76	0.006	0.006
-2.0	-76	0.006	0.006
-2.5	-76	0.006	0.006
+1.5	+76	0.006	0.006
+2.0	+76	0.351	0.006
+2.5	The air barrier system failed structurally at +2.0 kPa.		

D) Observations And Comments

The air leakage tests indicated an air leakage rate of 0.006 l/s/m^2 at 75 Pa for test specimen # 10. This value is approximately seventeen times smaller than the value suggested during the Building Science Insight'86 for moderate inside climate of 0.10 l/s/m^2 at a pressure difference of 75 Pa. The air leakage verification tests carried out after each of the structural tests, performed before the +2.0 kPa gust load test, indicated essentially no change in the air leakage rate of the assembly (see Section C). After the +2.0 kPa gust load test the air leakage rate increased to 0.351 l/s/m^2. This increase was caused by a structural failure of the assembly .

The air barrier system performed structurally through all the sustained load and gust load tests under negative pressure difference. That is, the air leakage rate did not change and no physical failure of the components of the asssembly was observed. Under positive pressure difference the system failed structurally during the 2.0 kPa gust load test. At approximately +2.0 kPa the top gypsum board pulled off from the screws at one end (see Photo 10-1).

Test specimen # 10 air barrier system is very air tight but the attachment of the gypsum boards to the supporting structure requires more attention. The double fastening technique is a possible answer to the assembly attachment weakness. With a slight modification in its fixation to the supporting structure, test specimen # 10 might perform structurally through the specified structural tests. Test specimen # 7 and # 10 are similar in their design and structural performance. In both cases, gypsum board is used to support the load under positive pressure differences and structural failure occurs during the +2.0 kPa gust load test. One can question the need of the additional material in test specimen # 10 when a system such as test specimen # 7 provides similar air leakage and structural performances.

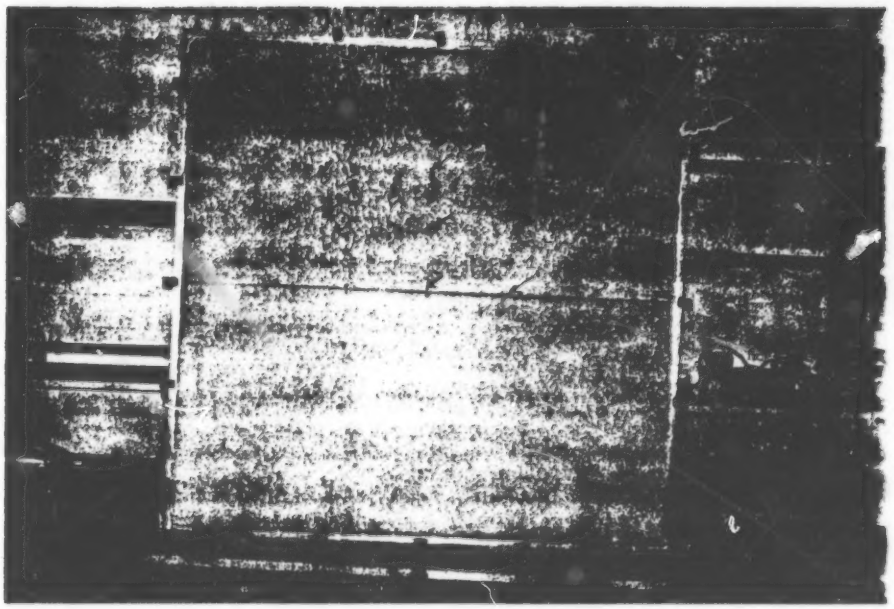


Photo 16-1:

Arrows indicate where the gypsum board pulled off from the screws.